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WHITE OAK LABORATORY

EFFECTIVENESS OF OVERHEAD SPRINKLER SYSTEMS FOR EXTINGUISHING FIRES ON HANGAR DECKS AND IN VEHICLE STOWAGE COMPARTMENTS

A Report on Phase I

5 NOVEMBER 1975

NAVAL SURFACE WEAPONS CENTER
WHITE OAK LABORATORY
SILVER SPRING, MARYLAND 20910

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The capacity of existing overhead foam dispensing sprinklers to extinguish fires shielded by aircraft and/or vehicles was measured under the crowded conditions encountered on hangar decks and in ships holds. Simplified shadowing geometries were used in a series of 10 foot diameter. JP5 fires extinguished with AFFF at application rates ranging from .16 to .22 GPM ft^{-2}. Findings from these model fires were confirmed in a series of 40 foot by 40 foot fires under full sized trucks and aircraft wings.

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Until the flames are knocked down, a substantial fraction of the agent is lost in the fire plume; however, the extinguishment time is controlled primarily by the rate of foam migration under the aircraft and vehicles. The existing sprinklers extinguished the burning JP5 and would provide protection for the ship but aircraft in the flames will suffer serious damage before the fire can be extinguished from overhead. The migrating foam does not cover or extinguish shielded combustibles that extend above the liquid fuel; consequently, the many tires on the stowed vehicles continued to burn and, unless extinguished by hand lines or other means, soon reignited the JP5. In order to prevent damage to aircraft and vehicles, additional applicators are required to apply agent directly to the seat of the fire.

5 November 1975

NSWC/WOL/TR 75-153

EFFECTIVENESS OF OVERHEAD SPRINKLER SYSTEMS FOR EXTINGUISHING FIRES ON HANGAR DECKS AND IN VEHICLE STOWAGE COMPARTMENTS
A Report on Phase I

The work reported here is part of a continuing study of detection and control of fires in the shipboard environment. This phase of the program is concerned with problems encountered in dispensing suppressants when parked vehicles represent an obstruction to the normal flow of AFFF. The program is under the technical cognizance of the Naval Sea Systems Command and Naval Ships Engineering Center under Task Area S4643.

The authors gratefully acknowledge the assistance and contributions from their colleagues, N. J. Alvares, S. J. Wiersma, D. J. Holve, D. J. Petro, and the LLL Site 300 Fire Department.

LEMMUEL L. HILL
By direction

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1.0 INTRODUCTION

At the present there is some uncertainty regarding the ability of existing sprinkler systems to cope with fires in crowded hangar decks and stowed vehicle spaces. Two problems are involved. First, the aqueous film forming foam (AFFF) exhibits considerable difficulty in penetrating the fire plume. Some agent is lost in evaporation and some is carried away by the buoyant forces. Second, the parked aircraft, yellow gear or vehicles shield a large area of the deck from the descending foam and thus preserve pockets of fire under equipment where flames can do the most harm. Specifically, the objectives of this program are to (1) establish the operational capability of existing overhead sprinkler systems and (2) develop criteria for the design of optimal extinguishing systems for such situations.

The approach is divided into two phases, one concerned with evaluating existing systems and the other providing for remedial measures if the systems demonstrate deficiencies. This report embraces the three steps involved in Phase I; i.e., (1) to survey the sprinkler systems, aircraft and vehicle parking patterns, and establish the test parameters of concern, (2) to determine the performance of single sprinklers in small fire tests involving various shadowing patterns, and (3) to conduct tests with full scale aircraft components and vehicles. Step I is covered in the background information of Section 2.0 which includes the shadowing characteristics of aircraft and vehicles in typical parking patterns and the pertinent test parameters. Sections 3, 4, and 5 describe the procedures and results for simulated aircraft shadowing in small fire tests, small vehicles in small fires, and the full scale tests respectively. These results show that a typical sprinkling system can protect a steel ship structures, but a serious fire will damage the aircraft and/or vehicles; therefore, the report concludes with a discussion of possible countermeasures and recommendations for Phase II Research.

2.0 BACKGROUND INFORMATION

2.1 Shadowing on the Hangar Deck

At the Naval Air Engineering Center in Philadelphia, parking patterns are developed by arranging scale model aircraft on a drawing of the hangar deck. Figure 2.0 illustrates the high parking density that can be achieved and the extent of shadowing involved. The numbers used in planning this study were attained by applying this technique to the CVA (N) 68 for a typical complement of aircraft. NAEC, Philadelphia, supplied the ships drawings and aircraft cutouts all scaled 1/8" to 1" and areas were obtained by counting spaces on crosshatched paper. About half the deck area is shadowed by the

aircraft. Unshielded or open areas were 58 percent in the forward bay, 60 percent midship, and 57 percent aft. Minimum opening widths ranged from 4 to 6 feet and the maximum distance foam would have to flow to reach the centerlines of wings and fuselages ranges from about 7 to 13 feet. Table 2.0 lists these flow distances for the various aircraft found in the parking pattern. The clearances under wings and fuselages are included along with other aircraft dimensions. In the experimental arrangement of Section 3, the available open area and foam flow distance provide a fair approximation to many of the situations encountered in the hangar deck.

2.2 Stowed Vehicles[1]

The fire suppression problem with vehicles differs from the aircraft situation in several important respects. First, the shadowing is more complete. Rectangular vehicles permit a higher packing density than aircraft geometries; consequently, in a plan view (Figure 2.1) vehicles typically cover 75 to 80 percent of the available area, compared to about 40 percent with aircraft. Furthermore, military trucks will catch and hold much of the foam, while with aircraft the foam runs off the smooth rounded surfaces and ultimately reaches the deck. In the elevation view (Figure 2.2) vehicles average considerably less clearance above the deck than is observed for aircraft and the adjacent vehicles form narrow steep canyons for the agent to traverse. This canyon effect is further accentuated by the low overhead clearance which frequently is only 8 to 14 feet above the deck. Second, the vehicles are stowed in a loaded condition; therefore, the fuel loading is high, particularly in Class A fire materials. When the ships are crowded, the fuel loading is further enhanced by stowing gear under the vehicles. Finally, when vehicles are stowed in the holds of ships like the LKAs, the hatch openings introduce sizeable unsprinkled areas; e.g., about 20 percent of the deck area.

Table 2.1 lists the ship plans examined, their vehicle stowage areas, overhead clearances, types of vehicles carried, and comments on the stowage pattern. When the configuration of the ship and the trucks permit, the spacing between vehicles is only 1 or 2 feet except for 3 or 4 foot wide fire lanes. Usually, there is at least one fire lane and sometimes two running the length of the stowage area. In landing ship docks, such as the LSD and LPD (Figures 2 and 3), the boats in the well-deck are also loaded with vehicles; e.g., LCUs hold four vehicles.

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[1]John Donnally of the Philadelphia Damage Control School was very helpful in outlining various fire problems associated with stowed vehicles. Major Gruning at the Navy Amphibious Base in San Diego provided detailed information about the procedures for vehicle stowage along with loading plans for typical operations.

Various safety regulations are employed to provide fire protection through prevention. For example, fuel is carefully controlled. The vehicles are loaded with three-quarters of a tank of gasoline to minimize the ullage while avoiding the possibility of spillage. Five gallon expeditionary cans on the vehicles must be either filled and checked for leaks or empty and purged. Tank trucks are stowed empty and purged on the weather deck until they are filled from the ship's supply just prior to debarkation. Ignition sources are controlled by disconnecting the truck batteries, prohibiting smoking, and restricting access to the vehicle stowage areas.

2.3 Pertinent Parameters

Table 2.2 summarizes the parameters deemed pertinent to hangar deck fires - some can be controlled, some can be measured quantitatively, and some can be observed only qualitatively. For convenience, the parameters have been divided into three categories according to their function; (1) experimental variables, (2) fire characteristics, and (3) evaluation parameters. Most of the items listed under environment, fuel, and suppression are under control during the experiment although not sufficiently to insure identical fires. Therefore, some fire characteristics are measured or observed to assist in evaluating the extinguishment efficiency. Finally, the evaluation parameters are yardsticks to be used in evaluating suppression efficiency.

3.0 10 FOOT DIAMETER HANGAR DECK FIRES

3.1 Objectives for Small Fire Tests

The small fire tests were designed to answer several types of questions. First and foremost, we wanted to know whether an overhead sprinkler could extinguish or control a Class B fire where the shadowing was comparable to that provided by typical Navy aircraft. Second, there were a host of questions concerning the effects of the experimental parameters on the fire characteristics and effectiveness of extinguishment. Third, these small tests were to provide design information for the full scale tests; e.g., the required test area, number and arrangement of sprinklers, foam quality, total quantity, and discharge rates. Finally, there is the important question of extrapolating results from the simple small model fire to the complex full scale situation. Many more variables can be examined in the small fires than time and money permit with large burns. At this point, a distinction should be made between "Modeling" or Simplification and Scaling a fire test. These 10 foot fire tests were models of the prototype hangar deck fire; i.e., the experimental environment was simplified, particularly the shadowing obstructions, but specific burning rates, foam application rates, nozzles were all full size. In contrast scaling involves changes in other dimensions besides the fire area.

3.2.1 Foam Application Rate

Figure 3.0 shows the experimental arrangement designed to provide the specified application rates of 0.16 and 0.22 GPM per foot^2 at operating heights of 15 and 25 feet with either the Grinnell Pendant or upright foam nozzles. Since a single nozzle could not produce the desired application rates, an adjustable array of four nozzles was used in the small fire shadowing experiments. The nozzles, a 200-gallon tank of pre-mixed AFFF solution, and an electrically driven pump were mounted on a frame structure which was lifted by a fork lift truck to provide the 15 and 25 foot sprinkler heights. Nozzle spacings of 30 inches and 8 feet were obtained with a selection of pipe nipples. Pumping rates and the agent consumed in each test were measured with a manometer on the water tank. Individual nozzle discharge rates were adjusted to 15 GPM with valves in the four parallel pipe lines. Application patterns and discharge rates were measured by weighing the foam collected in the arrays of sampling pans shown in Figures 3.0(a) and 3.1(a and b). Initial nozzle spacings and orientations were established using the black plastic foam recovery sheet and sampling pan array shown in Figure 3.1(c). A 20-second pattern and rate calibration run followed each extinguishment test. During extinguishment, the foam draining through the fuel and the surface deposit was collected in crystalizing dishes arranged to evaluate the shadowing effect (Figure 3.0(c)).

3.2.2 Foam Quality

During the 20-second discharges for pattern and rate calibration, samples also were collected to determine the expansion ratio and drainage rate. These samples were collected by the NRL Technique; i.e., with a large funnel in the top of a one liter graduate (Figure 3.1(b)). Determinations were made in accordance with NFPA Instruction 412. Since the foam was quite wet; e.g., expansion ratios were about four and the 25 percent drainage times were about one minute or less, prompt action was required to obtain the initial readings. Foam concentration was controlled by pre-mixing the solution in the 200-gallon tank. The 6 percent concentrate in a water solution was stirred thoroughly to insure uniformity.

3.2.3 Fire Environment

Three factors made up the fire environment; (1) the fuel pan and substrate, (2) the shadowing obstructions installed in the fire, and (3) the ambient wind. Figure 3.2 shows the 10 foot diameter fuel pan and the pipe framework for supporting the obstructions. The fuel floated on about an inch of water. Thermocouple and radiometer ports in the bottom of the pan provide for monitoring the fuel and combustion zone. In the last test of the series, the effect of a steel deck was simulated by placing a steel plate just below the surface of the fuel. During the preburn period, the fuel level dropped sufficiently to expose the steel to the surrounding flames which heated the metal well above the boiling point of water.

Figure 3.3 shows plan views, cross sections, and designations for the various obstructions used with the 10 foot diameter fires. Arrangements (1), (2), and (3) correspond to wing and tail sections with various drainage characteristics. In Configuration (1) foam from the topside of the wing could drain into the fire at several points; consequently, the foam flow distance over the fuel was reduced to about 2 1/2 feet. In Arrangements (2) and (3) the 5 foot flow distance was maintained but all the foam drained either into the fire or out of the pan depending on the slope of the simulated wing. The aluminum tail section protruding over the edge of the steel plates provided a qualitative indication of the damage that could be encountered in real aircraft structures. Since smoke obscured the tail section during the crucial part of the fire, the onset of melting was indicated by the falling stool pigeon shown in Figure 3.2. The melting aluminum released the support wire for the pigeon. Arrangement (4) represented a low clearance vehicle such as the yellow gear and handling equipment employed on the hangar deck. Arrangement (5) simulated a fuselage where the curved sides provide a potential for foam to flow inside the shadow line before falling to the deck.

Ambient winds were the principle uncontrolled variable. Two effects contributed to the dispersion in the data: (1) foam displacement and (2) flame tilt. When the velocity was modest, constant, and remained in one direction the mobile nozzles were moved upwind to maintain the foam pattern uniform over the fire bed. Obviously, this maneuver was ineffective against turbulent or gusting winds. Flame tilt was a more serious matter because a little breeze deflects the column more than the foam is displaced and a little tilt substantially reduces the length of plume that must be penetrated by the foam. Consequently, burns were conducted early in the morning when the air was calm.

3.2.4 Fuel

JP5 was used throughout the test series. Fuel thicknesses ranged from 1/2 inch to 1 inch at ignition; consequently, the water substrate temperature never reached 140°F. In the 10 foot diameter fire pan, 1 inch of fuel equals 40 gallons or approximately one drum.

3.2.5 Burning Rate

The three fire characteristics of concern in Table 2.2 are burning rate, geometry, and column aerodynamics. Only the first two parameters were measured, the third; i.e., column behavior, was characterized approximately by visual observation. During the equilibrium burning phase of the fire, about 8 1/2 gallons of fuel were consumed per minute. Burning rates were measured with the hydrostatic load cell manometers described in NOLTR 73-87[2]. The manometer was

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[2] "A Mobile Field Laboratory for Fires of Opportunity", NOLTR 73-87, R. S. Alger and J. R. Nichols

calibrated against fuel samples collected in a sampling thief, a technique also described in NOLTR 73-87.

3.2.6 Flame Geometry

Flame geometry and the tilt of the column were measured from time lapse motion pictures. Figure 3.4 shows the camera locations with respect to the fire bed and other instruments. These Super 8mm cameras record one frame per second and simultaneously apply an indicator mark on the visigraph record so that each picture can be synchronized with the other recorded data. A 16mm manually operated cine camera and 35mm still cameras provided additional coverage.

3.2.7 Ignition Procedure

For ease of ignition, the JP5 was primed with about a quart of gasoline along the upwind edge of the pan. After full involvement, the JP5 was allowed to burn for 30 seconds before suppression commenced. The times for the various events from ignition to end of suppression are recorded in Table 3.0.

3.2.8 Foam Application Density

A model for extinguishing Class B pool fires with AFFF has been developed in AGFSRS Reports III, V, VI, VII[3]. This model begins with a description of events that commence when foam arrives at the surface of the burning fuel. Extinguishment results from three effects by which the AFFF reduces the rate of fuel evaporation to a level that can no longer support combustion; i.e., (1) the foam in contact with the hot fuel turns to steam and quickly cools the surface to the boiling point of water, (2) the foam provides an efficient thermal barrier to reduce energy feedback from the combustion zone to the fuel, and (3) the thermally stable fluorocarbon constituent in the foam forms a vapor barrier over the surface and further reduces the rate of fuel evaporation. With JP5, the three effects operating together can readily reduce the rate of evaporation by a factor of 10^3. The minimum agent required for extinguishment; i.e., "the critical application density" for JP5 under these experimental conditions is about 0.7 gallon of AFFF per 100 feet^2 which is about the amount required to cool the surface of the fuel to 212°F.

Precise values of the critical application density are difficult to obtain experimentally because some foam is always lost in transit between the nozzles and the fuel surface. With overhead foam nozzles these losses include foam carried away by the updraft or

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[3] "Basic Relationships in Military Fires Phases III, V, VI, and VII", R. S. Alger and E. L. Capener, DOD-AGFSRS-75-4 dated May 1975, Unclassified. DOD Aircraft Ground Fire Suppression & Rescue Office, Wright-Patterson Air Force Base, Ohio 45433

evaporated by heat in the fire plume. The magnitude of these losses is an important factor in evaluating the performance of an extinguishment system. In evaluating these simulated hangar deck fire tests, the application densities obtained by multiplying the application rate by the extinguishment time are compared to a critical application density of 0.7 gallon per 100 feet^2.

3.2.9 Extinguishment Time and Pattern

These two factors are important in determining damage that can be inflicted by the fire. For example, long extinguishment times normally permit more damage to the simulated aircraft than short times unless the extinguishment pattern keeps the flames away from critical portions of the structure. In these experiments the nozzles were turned off as soon as it appeared that sufficient foam was in the fuel pan to complete the suppression of a few remaining flames. Occasionally we were over zealous, the extinguishment did not coast to completion and a small hand line was used to dispatch the remaining flames. Unless specifically noted, at least 90 percent of the fire area was extinguished with the overhead sprinklers.

Besides the usual observations and photography, some information about the suppression pattern and the rate of foam migration was obtained from the thermocouples, radiometers, and sample collectors located in the fuel pan. At the beginning of each burn, the thermocouple junctions were located just below the fuel surface. During the preburn period, the receding fuel would expose the junction and the registered temperature would rise abruptly. When foam is applied, thermocouples in the row under the wing obstruction cool successively as the foam progresses from the exposed area to the shadowed edge of the pan. Consequently, foam flow rates can be estimated from the thermocouple time temperature records. Similarly the radiometer records indicate when flames have been extinguished overhead. Difficulties with the visicorder limited the records of temperature and radiation to the later part of the series.

3.3 Results and Discussion

3.3.1 Application Rates

3.3.1.1 Effects of Nozzle Type and Position on Application Rate

Table 3.1 summarizes the application rates obtained in the eight permutations of Pendant and upright type nozzles, 30 inches and 8 foot spacings, and 15 foot and 25 foot elevations. Overall the range extended from 8.0 to 32 GPM per 100 feet^2; i.e., a somewhat wider range of values than initially specified. None of the three variables exhibited an overriding influence on the application rate. For example, when the nozzle types are compared at the same elevation and spacing, the pendant nozzles gave the largest application rate more frequently then the upright nozzles but the situation is not universal. Nozzle heights in the range from 15 to 25 feet produced

no consistent effect on the application rate. Similarly, nozzle spacing was not a controlling factor. Although the 30-inch spacings produced all the largest values, some of the other application rates were smaller than or equal to the 8 foot test values.

3.3.1.2 Effect of Wind on Application Rate

Ambient wind is the other factor contributing to the application rate. The small letters beside the application rate values indicate the state of the ambient wind velocity during the suppression test. Since the horizontal position of the nozzle assembly was adjusted to compensate for the wind, the values in Table 3.1 indicate aiming ability as well as foam dispersion by the wind. For the most part the largest application rates were obtained with zero or small wind velocities. Unfortunately, the combination of a small array of nozzles and a small fire is particularly susceptible to wind motion. Presumably with the larger nozzle arrays in actual hangar decks and in the large scale tests of this program, such ambient wind effects will be less important.

3.3.2 Fire Behavior and Extinguishment

In this section the principle questions are (1) can the overhead sprinklers extinguish fires under obstructions such as aircraft or other vehicles and (2) how efficient is this approach to fire suppression? Briefly the answers are respectively yes and not very. The more detailed discussion commences with a description of the temporal behavior of the fire and extinguishment. Next the influence of the experimental parameters on the extinguishment time is examined and finally the problems of increasing suppression efficiency are discussed.

3.3.2.1 General Behavior of the Fire and Extinguishment

Table 3.0 summarizes some of the spatial and temporal features of the fires involved in Tests 17 through 47. Following the first three columns that identify the test, nozzle arrangement, and obstruction, the table gives a qualitative description of the wind effects. Column 4 lists the approximate tilt angle for the flames away from the vertical. When the angle exceeds about 15^{o} some of the sprinkler heads are outside the smoke plume as indicated in column 5 and not as much foam is carried away in the plume, column 6. In column 6 the yeses are positive observations of foam carried aloft but the noes may indicate a lack of detection because of poor observation positions. Columns 7 and 8 list the times from ignition to full involvement of the entire fuel area and the extinguishment respectively. The principle factors controlling flame spread to full involvement were the fuel temperature, wind, and residual AFFF film from preceding tests. Generally the long initiation times correlate with calm air conditions. Between full involvement and suppression a 30-second preburn applies to all tests except No. 44 where the preburn was extended to 152 seconds.

When the sprinklers were turned on, extinguishment usually occurred quickly in the exposed fuel areas; e.g., 10 to 15 seconds. In the unobstructed fires, 40 to 44, the average extinguishment time was 15 seconds and the open half of the other fires were usually out in about 10 seconds. When the flames were tilted, extinguishment started on the upwind edge and progressed down wind across the pan. In still air the pattern is not so pronounced but in general suppression progressed inward from the outer rim of the pan. As would be expected, most of the time was required for foam to flow under the shadowing obstructions. The sequence of photographs in Figure 3.5 illustrates this progression under the still air and type 3 obstruction conditions of Test #26. Column 9 shows the total fuel consumed during the tests and ten indicates the degree of extinguishment when the nozzles were turned off. In only three cases the foam was making little progress when the application was terminated; i.e., Tests 24, 27, and 31. Test 31 was well controlled as indicated by the small residual flame area; however, 24 and 27 were still serious fires. In both 24 and 27 the combination of essentially zero wind and a close nozzle spacing caused a large fraction of the foam to be carried aloft in the fire plume. Consequently, the time to extinguish the open area was lengthened to 55 and 30 seconds, respectively. These tests were terminated when it became apparent that the foam was making very slow progress and the simulated wing developed a substantial sag. AFFF applied with a garden hose readily extinguished these fires.

In both Tests 24 and 27 the aluminum aileron section melted flush to the supporting steel plate. In subsequent tests where the stool pigeon was attached to a particular part of the aluminum structure, melting always occurred in the aluminum skin but sometimes the internal supporting struts survived. Usually the skin would begin to melt before full involvement of the fuel; e.g., 90 to 100 seconds after ignition.

3.3.2.2 Effect of Experimental Parameters on the Extinguishment Time

The four variables of concern in this section are (1) the specific application rate for the agent, (2) shadow shield configurations, (3) wind, and (4) substrate. In the following paragraphs, the extinguishment times or more precisely the agent discharge times to achieve the degrees of extinguishment listed in Table 3.0, are examined for correlation with these parameters.

For an ideal extinguishment with AFFF applied uniformly and simultaneously over the entire fire area, the extinguishment time is inversely proportional to the application rate as indicated by the hyperbolas in Figure 3.6. When the extinguishment times from Table 3.0 are added to Figure 3.6, the resulting shotgun pattern exhibits no correlation to either the ideal curves or the application rate. Therefore, it must be concluded that over the range of application rates examined other factors are controlling the extinguishment time.

Figure 3.7 shows the discharge times cataloged according to the obstruction configuration. Average values are indicated by the dashed lines and the symbols indicate the nozzle -- height - spacing

combination. While some of the configurations exhibit sufficient scatter to suggest the importance of other variables, there is obviously a substantial impact of obstruction geometry on extinguishment time. Configurations 3 and 4 definitely provide more protection for the flames than obstructions 1, 2, and 5. Arrangements 2 and 5 dumped all the runoff foam into the fuel bed thereby contributing to the flow under the structure. Conversely, Arrangements 3 and 4 removed the runoff from further participation by dumping it outside the fuel pan. Structure 1 leaked considerable foam through the center joint effectively reducing the foam flow distance to the back of the pan. These measurements demonstrate an obvious sort of conclusion that in the absence of other overpowering forces the extinguishment by foam flow under an obstacle will progress fastest under the edge offering the greatest runoff.

The second correlation in Figure 3.7 repeats the cataloging of extinguishment times according to obstruction geometry but the symbols have been changed to indicate the wind conditions. Since wind effects can either help or hinder extinguishment, the legend has been coded to indicate velocity according to angle of flame tilt and direction. When the wind direction assisted foam drift toward the remaining flames, the wind was assumed to help suppression. Opposing breezes are classified as hindering.

When the velocity is zero or very low (circles) the column carries the maximum foam aloft and minimizes the agent reaching the pan; consequently, the hollow circles should appear well up in each category along with the symbols for hindered foam flow. Conversely, the helped symbols should congregate toward shorter extinguishment times. Only Obstacles 2 and 3 experienced more than one wind direction and all but one of their points congregate in the direction expected from wind effects. Obstacle 4 was only 6 inches above the fuel surface; consequently, it was difficult to establish how much the modest winds assisted although the direction was favorable. With the fuselage mock-up; i.e., No. 5, almost any wind direction was helpful since foam ran off both sides of the structure.

Substrates were not examined in detail but the steel deck simulation described in Section 3.2.3 was used in test 47. Figure 3.8 shows the progression of extinguishment first over the liquid surface and finally next to the exposed hot steel. Although the wind was in the helping direction this arrangement required the most agent of the Class 5 obstruction extinguishments. As the fuel burned the surface of the steel became exposed then heat from the flames caused further warpage so that the plate was well above the liquid level at the end of the test as shown in Figure 3.8(d).

In summary, both the obstacle geometry and the wind exert a strong influence on extinguishment in contrast to a negligible impact from modest changes in discharge rate. Apparently the controlling factors are foam spread time and losses during penetration of the fire plume. In a ship's hangar deck, the higher wind velocities can be eliminated; however, the zero wind condition created the most difficult

environment for extinguishing a fire. If the quantity of fuel available on the hangar deck is small and the extinguishing system is activated before large areas become involved, the sprinkler system should extinguish the fire in times camparable to the still air conditions in these experiments because suppression can commence at the edge of the fire and the foam flow distances are comparable. However, with larger fires the plume penetration problem may be even more severe than in Tests 24 and 27.

3.3.2.3 Application Densities and Extinguishment Efficiency

This section is concerned with extinguishment efficiency and the amount of damage that can be inflicted on a ship and its contents before the fire is brought under control. First we will examine the foam lost in penetrating the flames, then the efficiency of the flow process for transporting foam to obstructed or shadowed regions. Table 3.2 summarizes the application densities; i.e., (application rate x discharge time) and the agent collected in the crystalizing dishes during each run. When no obstructions were present; i.e., Tests 40 through 44, the average application density for extinguishment ranged from 3.5 to 5 gallons of solution per 100 feet^2 of fire. The critical application density measured for JP5 in this same pan with a low level application trajectory that minimized plume penetration losses was about 0.7 gallon per 100 feet^2. Consequently, about 4/5 of the agent appears to be lost either in penetrating the plume or wasted in a non-uniform pattern upon arrival at the fuel surface. Although the overhead sprinkler efficiency is not impressive by this comparison, the densities achieved do compare quite favorably with many other test results.

In the ideal extinguishment model mentioned in Section 3.2.8, a perfectly uniform deposit of foam would extinguish the fire simultaneously at every point and essentially all of the agent would evaporate in cooling the fuel down to the boiling point of water. Only a thermally stable vapor barrier a few microns thick would remain on the surface. Under these conditions, no agent would sink to the bottom of the fuel and appear in the collection dishes. Consequently, the amount of agent collected in the dish indicates the excess arriving at that point in the fuel bed because of a non-uniform application pattern, overkill, or foam migration on the surface. Agent arriving in drop form instead of as a floatable foam might also contribute to the amount collected in the crystallizing dishes provided it arrived after the fuel had cooled below 212°F. At the end of the preburn period the surface of JP5 is about 420°F and water turns to steam before it can penetrate the fuel layer.

In Tests 40 through 44 the collection pattern indicates some non-uniformity in the deposition pattern. Dish 1 always had the highest deposit and Dish 5 the lowest. Since these 5 tests were conducted on the same day, the gradient reflects both the nozzle variables and the ambient wind. At other times different patterns were obtained; e.g., in Test 10 the gradient was reversed. Columns 9 and 10 in Table 3.2 show the average agent density collected in the dishes and the agent assumed to be lost in transit where:

Lost Agent = Application Density - Critical Application Density - Agent in Dish

Finally the last column tabulates the ratio:

$$\frac{\text{Lost Agent}}{\text{Application Density}}$$

Without obstruction, about 50 percent of the applied solution remains unaccounted for and presumably was carried away or evaporated in the fire plume.

The obstruction geometries had a substantial impact on both the extinguishment efficiency and the foam deposition pattern. With Obstacles 2, 3, and 4 the application density exceeded the critical value by factors ranging from 10 to 50; therefore, the foam is not being employed very efficiently. The dishes under the obstruction; i.e., No. 4 and No. 5, collected small amounts of agent as would be expected. In some cases where zero's are recorded the fuel level had burned down below the rim of the dish thereby impeding the collection, but in most cases just sufficient foam had arrived to extinguish the fire. Obstacle Arrangement (2) drained considerable agent from the top of the simulated wing into the fire bed; consequently, Dish No. 3 and sometimes No. 2 collected very large quantities of agent sufficient to unbalance any averages for the pan; i.e., the deposited average sometimes exceeded the average applied density. With Configurations No. 3 and No. 4 the drainage mostly fell outside the pan; therefore, the crystallizing dish samples can be averaged more reliably. In Tests No. 24 and No. 27 where the fire plumes were particularly effective, the apparent losses in transit reached 80 percent. When application densities were less than 15 gallons per 100 feet^2 the transit loss remained below 50 percent.

The efficiency of foam flow is indicated qualitatively by the distribution in the sampling dishes except where a dish was obviously under a drainage point from the wing above. In numerous cases the density collected in the exposed areas is ten times the amount under the obstruction, but this is not always the case and the factors responsible for variation are not obvious.

Another type of correlation is illustrated in Figure 3.9 where the application density is plotted as a function of the application rate. The symbols correspond to the different shadow obstructions. For ideal extinguishment the density should be independent of the rate of application. When the foam had to flow under the Obstruction Arrangements (2) and (3), the application density increased substantially at the higher rates indicating again that the rate of application was not the controlling factor.. Presumably the application density for the unobstructed fires; i.e., triangular symbols, should remain independent of the rate effects. Unfortunately, the variation in rate is not sufficient to test this point.

Finally there is the question of potential damage to the ship and contents during the fire and extinguishment. The qualitative observations with the aircraft tail sections protruding over the steel shadow assemblies demonstrated the effects on the thin aluminum skin; i.e., where flames made sustained contact the aluminum melted as described in Section 3.3.2.1. In other cases where the wind-blown flames did not contact the aluminum portion of the obstruction, melting did not occur. Although the aluminum ribs and other heavy gauge supporting structures did not always melt, melting is not required to weaken the structure. Many of the high strength aluminum alloys employed in aircraft lose substantial strength if annealed to such relatively low temperatures as 350° to 400°F. Consequently, a very short exposure in the flames can produce permanent damage. Another type of damage observed involved plane sections assembled with adhesives. Fire destroyed the adhesive and the metal sections separated before the aluminum reached its melting point.

3.4 Conclusions

3.4.1 Existing hangar deck sprinkler systems are adequate to extinguish moderate sized fires where aircraft partially shield the flames from direct foam application. The performance with fires greater than 10 feet in diameter will be discussed in Section 5.0.

3.4.2 As anticipated, the extinguishment time is controlled by the rate of foam movement under the shadow obstruction; consequently, the time is sensitive to the pattern of foam draining off the obstruction. Moderate variations in the application rate have a negligible effect on the extinguishment time.

3.4.3 Extinguishment with overhead foam sprinklers is not an efficient method of applying AFFF to a hangar deck fire. Fifty to 80 percent of the agent can be lost in penetrating the fire plume and excessive deposits are received in the exposed areas while waiting for foam to migrate under obstructions. A low trajectory application of the foam under the obstructions could extinguish the same fire with 1/10 to 1/50 the amount of agent.

3.4.4 The existing sprinklers will provide protection for the ship but aircraft in the flames will suffer serious damage before the fire can be extinguished from overhead. As long as the ship is the principle concern and the aircraft are considered expendable, the overhead system is adequate for moderate sized pool fires. The experiments reported here did not include spilling, cascading, spraying, flowing, or other forms of three dimensional fuel fires; however, past experience indicates that overhead nozzles are ineffective against such fires.

3.4.5 In new ship design alternate application methods should be explored to eliminate the inefficiencies and restrictions inherent in the application of AFFF from overhead nozzles.

4.0 VEHICLE STOWAGE TEST FIRES IN 10 FOOT DIAMETER PAN

4.1 Objectives

These preliminary tests were conducted to answer the questions encountered in the design of the larger burns planned for Site 300. Since fire characteristics reflect their environment, the first question concerned the effects of the low vehicle clearances and spacings on ignition, fire spread, and the steady-state burning rate. Second, there was the question of extinguishment and the amount of AFFF required providing control could be achieved. Since the open area with vehicles is only about half the value for the aircraft and the geometries are not as conducive for run off, larger application densities could be anticipated. Furthermore, the structures will not melt and expose more of the fire bed. Finally, the presence of Class A materials in positions exposed to flames add both a third dimension to the fire and change the burning characteristics. In the interest of economy, we were also interested in the performance of 3 percent versus 6 percent solution concentration for this type of application. One conclusion of the AGFSRS program was that the critical application density was essentially the same for 3 and 6 percent solutions of FC 200 when applied uniformly and simultaneously over the fire bed. Presumably, such foam characteristics as drainage rate and burn back resistance will influence the survival of the foam in its migration into the shadow areas; therefore, the 6 percent solution with its higher expansion ratio and stability might exhibit an advantage.

4.2 Experimental

The pertinent experimental variables and evaluation parameters were controlled and measured as described in Section 3.2. Figure 4.0 shows the arrangement for the vehicle burns, with a derelict Nash Rambler covering half the fuel bed and a steel plate covering all but a 2 foot wide aisle in the remaining area. Typical combat vehicles have canvas tops; therefore, the top of the Rambler was removed to provide foam access to the interior. Since this procedure insures soaked upholstery, a fresh dry cushion was added for each test. In the first fire the upholstery did not ignite; consequently, in subsequent tests the upholstery was doused with gasoline and ignited along with the pool to insure a respectable Class A fire. Approximately 1/2 gallon of gasoline was also applied to the JP5 to assist with ignition. The gasoline tank in the vehicle was filled with water to eliminate any explosion hazard. The fires were considered to be controlled when the JP5 pool fires were extinguished at which time the only flames were from burning rubber tires in the protected areas under the fenders. These rubber tires were readily extinguished with a hand line. Foam characteristics and application densities were measured for a 20 second discharge immediately following each burn.

4.3 Results, Discussion, and Conclusions

The data summarized in Table 4.0 provide answers to the design questions along with some suggestions for dealing with vehicle fires. First, it appears that the vehicles modified the fire characteristics by reducing the rate of intensity build-up and the burning rate. Under the pan and automobile, the thickness of the flames visible to the fuel is severely limited by the obstacles; consequently, the energy radiation feedback is restricted and the fuel must evaporate at a slower rate, at least until the metal surfaces heat up enough to make a substantial energy contribution. With the 30 second preburn, the vehicles remain moderately cool and the burning rates were substantially below the tests without obstructions. The effect of vehicles on the flame spread rate; i.e., the time to full involvement cannot be determined from Table 4.0 because these factors were dominated by the wind and in some of the tests a residual AFFF film.

Second, the flame patterns reflect the influence of both the vehicle and the wind. In a dead calm, the airflow was radially inward around the periphery of the pan and the combustion plume remained over the 2 foot wide corridor between the vehicles. After the gasoline used in igniting the interior of the car burned out, the Class A fuel contribution to the overall fire was rather small; consequently, the JP5 corridor plume dominated the fire. Moderate breezes; e.g., in the 1 to 3 mph range displaced the plume substantially and caused flames to emerge along the downwind periphery of the fuel bed. Flames emerged only on the front and right sides of the automobile; consequently, the paint on the left side and rear was not scorched.

Third, suppression times and application densities were comparable to the values observed in the aircraft shadowing experiments. Both the 3 and 6 percent solutions successfully controlled the fires; however, the limited number of tests preclude a statistically significant evaluation of concentration effects. No difference in extinguishment time was observed in the unobstructed extinguishments and the shorter control time achieved with the 6 percent solution in the vehicle fires may be due either to the agent or the fact that burn 50 was less intense than fires 51 and 52.

Chronologically, the sequence of events following activation of the foam pump are as follows: with the 30 second preburns and slightly tilted fire plumes, the pipes and nozzles remained cool enough to emit foam immediately; however, in run 52 steam was generated for several seconds until the pipes could cool. No Class A fire developed in run 50, but in Tests 51 and 52 flames from burning upholstery and wood were extinguished in about 2 to 5 seconds, long before the pool fires were controlled. Since the only foam access to the pool was through the corridor between the vehicles, the foam had to extinguish flames in this region first and then flow under the obstruction. It appeared that vapors escaping from under the vehicles maintained a plume over the corridor after the foam had sealed the local fuel surface. The plate was narrower than the automobile; consequently, the flames under the plate were always extinguished

first. At the control time, the JP5 had been extinguished and only the rubber tires continued to burn under the fenders and out of range of the sprinklers. This sequence of events is illustrated in the series of photos in Figure 4.1. Figure 4.1(a) shows the fire at peak intensity just before suppression commences. In Figure 4.1(b) the fire in the car has been extinguished but vapors from under the vehicles still maintain a sizeable flame. Only a little fire remains under the car in Figure 4.1(c) and (d) the Class B fire has been extinguished and only the protected tires continue to burn shortly before the nozzles were turned off. The only disruption occurred when the drive shaft ruptured violently during Test 52 and displaced sufficient JP5 to momentarily produce a small fire ball behind the vehicle. Most of the Class A materials; i.e., wiring, hoses, airfilter, battery case, etc., were missing from the automobile, a factor that probably contributed to the lack of fires in the engine compartment.

These preliminary experiments lead to several simple conclusions that are applicable to modest size fires. First, the overhead sprinklers can control vehicle fires involving Class A and B materials. Second, hand lines or other auxiliary equipment will be necessary to complete extinguishment of fuels in the shielded areas. Third, a 3 percent solution of FC 200 is adequate for this type of fire. Fourth, the application density for control increases significantly when the fire plume becomes well established and carries away significant amounts of foam. Fifth, the close packed vehicles constitute a substantial heat sink and radiation shield; therefore, the fire develops; i.e., the burning rate increases at a slower rate than for an open pool fire. This factor is an advantage when fire fighting can commence promptly; however, "the most severe case" test will require lengthy preburn times; e.g., several minutes.

5.0 FULL SCALE TESTS AT SITE 300

5.1 Test Objectives

The full scale tests were designed to check the conclusions reached in Sections 3.1 and 4.1 with respect to three facets of the fire problem: (1) effects of the vehicles and aircraft structures on fire characteristics; i.e., burning rate and intensity of the fully involved fire; (2) the time history of damage development in the vehicles and structures; and (3) such suppression characteristics as the time and agent required to control the fire. Following the experience with burning tires (Section 4.3) some preliminary exercises in controlling these rubber fires were also incorporated in this series.

5.2 Experimental Apparatus and Procedure

5.2.1 The Fire Field and Foam Sprinkler System

Figure 5.0 shows the fire field ready for a typical test as observed from a hilltop camera station. Two test vehicles are parked under the sprinkler away on the fire bed. About 100 feet beyond the bed and progressing from the right are (1) a 2,000 gallon water tanker

used for the general water supply and mop-up operations, (2) the bumper truck and trailer mounted agent reservoir to supply AFFF to the sprinkler towers, (3) the instrument trailer which contains all the signal modification and recording equipment, (4) a trailer mounted electrical power supply, and (5) auxiliary vehicles. Another test vehicle and several aircraft wings are visible in the foreground. Cameras and radiometers are barely visible on three sides of the burn pad at the locations indicated in the instrument layout diagram in Figure 5.1. Figures 5.2, 5.3, and 5.4 show details of the foam supply system. Nozzle locations are indicated in the test bed diagram of Figure 5.2 Twenty-five nozzles are supported 8 feet on centers in a rectangular array by four towers that also supply the agent. This overly simplified arrangement assumes that the minor influence of nozzle spacing, height, and foam application uniformity observed in Sections 3 and 4 will apply here also; therefore, we did not attempt to find the optimum arrangement or spacing for a uniform coating of foam. Twenty-five nozzles at 15 GPM will supply enough agent to deposit an average of .22 GPM per feet^2 over an area of 1,700 feet^2; i.e., about a 40 foot square. Since each nozzle pattern is over 8 feet in radius complete overlap occurs between nozzles. Also, considerable agent will fall outside the 40 foot square thereby reducing the application density around the periphery. Most of the area occupied by the trucks receives agent from at least three nozzles and should average close to the .22 GPM per foot^2. Figure 5.3 shows the coaxial tower construction details, the provisions for keeping the agent and towers cool during a fire, and the method of installing the towers. Concrete piers support the tower baseplates below the rock substrate and watertight plastic membrane of the existing bed. Agent from the supply line flows through the 2 inch centerpipe to the distribution head that feeds the eight foam nozzles. When mounted at the ends of the feeder lines the nozzle height was 14 feet. A 4 foot nipple was inserted in each line to reach the 10 foot elevation. The coupling just below the distribution head facilitated assembly and alignment; i.e., each group of distribution pipes and nozzles was assembled on the ground, insulated with Kaowool and then hoisted as a unit into position. Prior to ignition the space between agent line and the 4 inch outer pipe was filled with water from a separate 1/2 inch copper line to keep the tower cool while immersed in flames. Since both pendant and upright nozzles gave the same results during the small fire tests, only Grinnell pendant nozzles were tested in this series. Figure 5.4 is a photo of the distribution pipes and nozzles in the 14 foot position. The 25th nozzle is supported on a 3/4 inch pipe between two of the towers. Guy wires from the tower extensions provide additional support for the distribution pipes. Figure 5.5 is a schematic diagram of the agent, water, and fuel systems. The agent containing either 3 or 6 percent FC-200 was pre-mixed in the 1,250 gallon tank mounted on a flat bed trailer. A standard 6 inch hard line connected the tank to the pumper truck which supplied agent at a dynamic pressure of about 90 psi and 375 GPM to the 2 1/2 inch fire hose leading to the tower piping system. Pressure and flow were controlled at the truck and the total agent discharged was measured with a manometer on the supply tank. Additional valves provided for balancing the flow at the header were not used. Total discharge rates were monitored by the pressure drop across a sharp edge orifice plate

in the 3 inch pipe line. Differential pressures were measured both with Bourdon type gauges and with pressure transducers and load cells that supplied signals to the instrument trailer. Prior to each test, the lines were charged with agent up to the 3/4 inch distribution lines; i.e., until agent started to flow from the nozzles. Tower cooling water was supplied by a temporary connection to the water tanker truck. After the towers were filled the tanker was disconnected and moved into position to supply water for the mop-up operation following sprinkler shutdown. This truck also supplied water to the fire bed when it was necessary to raise the fuel level with respect to the rock substrate. Lowering the fuel level was accomplished with the drain line connected to the bottom of the bed. Just before ignition about 400 gallons of JP5 was applied to the fire bed through four outlets connected through underground plastic pipes to the 5,000 gallon fuel trailer parked behind the berm.

5.2.2 Instrumentation

Figure 5.1 is a schematic diagram of the instrumentation. Burning rates were measured with a water cooled load cell type manometer buried under the mid section of Test Vehicle No. 2 as indicated in Figure 5.2. This cell measures the pressure from the water, fuel, and air above. Since the burning rate is proportional to the slope of the weight loss curve any constant change in the atmospheric pressure cancels out. Load cells are extremely temperature sensitive. Therefore, cooling water was supplied throughout the burn from an elevated 50 gallon drum. Temperatures at three locations in Test Vehicle No. 1 were measured with thermocouples; i.e., TC_1 was in the gas tank which had been filled with water. TC_2 monitored the drive shaft temperature and TC_3 was in the engine oil. When the aircraft wing was included in Test 5, four additional thermocouples were added to monitor temperatures at various locations in the aluminum structure. Radiometers measured the radiation field on three sides of the fire; i.e., R_1 through R_9, and calorimeters monitored the thermal insult to the aircraft wing during Test 5; i.e., C_1 through C_{10}. The radiometers are of the Gardon type mounted in insulated boxes along with self-contained cooling water supplies as described in NOLTR 73-87. Simple copper slug type calorimeters were mounted on a section of aircraft to measure the thermal insult and the protection afforded by insulation for companion experiments in the high performance ship program. Time lapse cameras on three sides of the fire recorded the flame height and geometry at one second intervals and put a mark on the visicorder record for each exposure. A 16mm camera on the hilltop and several 35mm cameras completed the film coverage. Finally the anemometer recorded the wind velocity and direction.

5.2.3 Ignition, Preburn, and Suppression

Approximately five gallons of gasoline were poured along the upwind sides of the JP5 pool to facilitate ignition and shorten the time to full involvement. Usually, two adjoining sides of the pool were ignited with a gasoline soaked torch. The time to full involvement

depended strongly on the wind velocity and ranged from 35 seconds to about 3 minutes. After full involvement, a preburn of about 30 seconds was allotted before suppression commenced. In Test 5 the preburn was extended to 5 minutes. Suppression times with the sprinkler system were limited to 3 minutes by the capacity of the agent reservoir. The burning JP5 was always extinguished by the time the nozzles were turned off and only the shielded Class A material remained to be extinguished with hand lines; e.g., tires, upholstery, wood parts of the truck bed, etc.

5.2.4 Mop-up Procedures

A variety of nozzles were used with the hand lines to extinguish the shielded fires. First, a Batel 1 1/2 inch nozzle with eductor drawing concentrate from a 5 gallon can of surplus FC-195 or 196 was used to extinguish shielded pockets of burning JP5 as shown in Figure 5.6(a). These pockets were next to the burning tires or under the truck body where obstructions held foam from the overhead sprinklers at bay and prevented complete coverage of the fuel surface. For example, the spare tire centered under the frame of truck No. 1 was particularly effective in maintaining a JP5 fire. Although difficult to distinguish in the black and white prints of Figure 5.6(a), these flames are readily apparent in the original color film. Most of the tire fires were extinguished with water supplied either through an adjustable 1 1/2 inch fog-straight stream nozzle or a 6 foot applicator on a 1 inch hard line as shown in Figure 5.6(b). In Tests 6 and 7 high expansion foam was applied to the burning tires. Figure 5.6(c) shows the steel window screen wrapped around two trucks to contain the foam and in 5.6(d) a Jet-X portable generator is filling the space between the trucks. Finally, in Test 16 PKP was manually applied to some of the burning tires.

5.3 Results and Discussion

5.3.1 Performance of Sprinklers in Absence of a Fire; i.e., Uniformity and Application Pattern

Figure 5.7 shows the sprinklers in operation at the 14 foot elevation and Figure 5.8 indicates the average application rates in GPM foot^{-2} measured at the various sample pan positions. Three of the diagrams are for water and the last two are with 3 percent AFFF. Wind directions and velocities are indicated by arrows and an associated value in mph. Both the reduced application density around the periphery mentioned in Section 5.2.1 and wind effects are apparent. The density variations at a particular sampling position; e.g., 20 percent and the low densities on the upwind side, are assumed to be wind effects while the low values at the corners obviously result from the nozzle locations. Since many of the values are in the .16 GPM foot^{-2} range, it was decided not to reduce the number of nozzles and increase the spacing for part of the tests to achieve a closer match to the .16 GPM foot^{-2} value. Also, because of the strong wind effect both on the spray pattern and the flame structure, most of the tests were conducted under still air conditions. Although the uniformity was far from ideal, the 10 foot diameter fires had indicated that

application density was a secondary factor in the extinguishment time; therefore, the nozzles were used without further lateral adjustment. Fortunately, the wind effects tend to cancel themselves; i.e., the tilt of the flames reduces the length of the hot column and thus the buoyancy forces that carry foam aloft; therefore, the light application densities on the upwind side are still quite effective.

5.3.2 Fire Characteristics

This section is concerned with the effects of the environment, particularly the wind and vehicles on those characteristics of the fire that could influence suppression. Characteristics of interest include the geometry and size of the combustion plume that has to be penetrated by the foam and flame heights, burning rates and radiation fields that indicate the intensity of the fire. Figure 5.9 shows fires for the four permutations of the two variables (a) has no wind or vehicles, (b) has wind at about 6 mph and no vehicles, (c) has no wind plus 30 percent of the total area covered by two trucks and an aircraft wing, and (d) has wind at about 6 mph plus 53 percent of the total area covered by four trucks and a collapsed aircraft wing. Without wind the columns in (a) and (c) have very similar appearances although the fire areas are different (a) has not spread to the full 40 feet x 40 feet indicated by the berm; therefore, two towers are still visible. Fire (c) has spread on fuel which escaped over the temporary berm during the loading of the trucks to a full 50 feet x 50 feet square. No vehicles or towers are visible and the flames and smoke appear to coalesce into a single column. Fires (b) and (d) indicate a substantial tilt to the upwind edge imposed by a very modest breeze. The thin layer of flames to be penetrated by the foam on the upwind side is readily apparent. Where the vehicles are present in (d) this tilt exposes both the upwind towers and the ends of the trucks. Obviously the trucks form holes in the flames although the smoke and flames appear to coalesce further up. The flame tilt and exposed towers should assist extinguishment. In all of the photos the flames extend beyond the field of view so the flame heights cannot be measured; however, Table 5.0 lists the burning rates and radiation fields which reflect the size and intensity of the fire. All values correspond to the conditions at the time suppression commences. Generally a 30 second preburn followed full involvement; however, in Test 2 the flame spread so slowly that suppression was commenced before the entire fuel area was involved. The effect of a longer than normal preburn time was examined in Test 5 where the fire was allowed to burn for 6 minutes following full involvement. Figures 5.10 and 5.11 show the temporal behavior of the burning rates and radiation fields respectively for these special cases as well as standard test fires. The presence of the vehicles apparently exerts little influence on the observed fire characteristics. In Figure 5.9 wind effects are prominent with respect to plume tilt but the vehicles do not appear to alter the geometry or size of the overall fire. Momentarily excluding fires 2 and 5 because of their departure from the standard preburn ritual, Table 5.0 suggests that the burning rate increases faster in the absence of vehicles; i.e., at the start of suppression, the burning

rates were slightly lower for the vehicle burns. However, during the long preburn of Test 5 the burning rate reached and at times exceeded the no vehicle values.

5.3.3.1 General Description

Here we describe the progress towards extinguishment in terms of the fire size as a function of time which in turn is directly related to the amount of agent discharged. Generally the behavior follows the description for the 10 foot fires in Section 3.3.2.1. Without obstructions, as in Tests 1, 2, and 3, extinguishment commences at the periphery and progresses inward as illustrated by the sequence of photographs in Figure 5.12. According to Table 5.1 the elapsed time between Figure 5.12(a) and (d) is about 10 seconds. The small fire remaining in (d) is outside the test area and beyond the range of the overhead sprinklers. With such short times it is difficult to distinguish between control and extinguishment; however, the agent discharge; i.e., nominally 5 gallons per 100 feet^2, was not sufficient to provide appreciable burn back protection. If residual flames such as those in Figure 5.12(d) are not promptly extinguished, the entire fuel bed can be readily reignited particularly in the presence of a favorable wind. In Test 3 the fuel did reignite and the second group of numbers in Table 5.1 apply to this rekindled fire. When vehicles were present in the fires, suppression progresses at a slower pace and Table 5.1 lists times when several recognizable stages are reached; e.g., (1) flame heights are reduced to the height of the nozzles, at this time the flames no longer coalesce into a single plume but exist as a group of individually burning regions. Subsequently, bursts of flame may exceed the nozzle height but most of the time the flames are lower; (2) the liquid fuel is extinguished in all open areas, flames do not exceed the height of the vehicles; (3) only the tires and JP5 immediately in contact with the rubber continue to burn. No further change in the burning pattern develops. Figures 5.13 and 5.14 illustrate these stages for Test 6 with two vehicles and Test 10 with four vehicles plus a wing, respectively. For example, in 5.13, (a) shows the flames just before the onset of suppression, in (b) the flames are about tower height and separated into several fires, and in (c) only the tires and adjoining fuel continue to burn. Flames from the spare tire under the truck on the left are clearly visible in (c). According to Table 5.1 state (1) was reached in .2 to 2 minutes, (2) in .5 to 2.9 minutes, and the remainder of the three minute discharge was in state (3). For a steel ship, the time to control the fires so they would not cause further damage to the ship was less than 2 minutes; however, when the tires are not completely extinguished, reignition of the JP5 ensues and the fire soon returns to full size. Such reignitions followed Tests 9 and 11. The first reignition was unintentional and occurred after the tires had smoldered for about 10 hours. Fire 11 was intentionally allowed to burn back and complete coverage was re-established in about 15 minutes.

5.3.3.2 Effect of Fire Size and Vehicles on Application Density for Control

Two considerations are of particular interest here (1) the zero obstacle case where variations in extinguishment time indicate how efficiently the agent penetrates the fire plume assuming comparable pre-fire pattern uniformities and specific application rates and (2) control times with real and simulated vehicles where foam migration distance determines the time. In the first case our lack of knowledge regarding the buoyancy and upward velocities in the flames at the nozzle locations preclude a definitive comparison of the extinguishment in the 10 foot and 40 foot fires; however, for geometrically similar flames and positions the velocity apparently increases with fire size in proportion to the 1/3 power. In going from 10 feet to 40 feet the velocity increases by a factor of about 1.6; i.e., a relatively small factor. Furthermore, inside the flames the velocity increases in some manner with the altitude and the relatively lower position of the nozzles in the 40 foot fires will nullify some of the diameter effect, so little difference in extinguishment time is anticipated in going from 10 to 40 feet. A comparison of Tables 3.0, 4.0, and 5.1 support this rationalization for the no vehicle burns. These tables also shown similar times for the foam to migrate under the vehicles and extinguish the burning JP5. For example, in Table 5.1, stage (2), generally occurs within 90 seconds as previously found in the small fires. Also, the number of vehicles appears to be of little consequence as long as the foam fed into the interstitial spaces and the migration distances remain reasonably constant; e.g., compare Tests 4, 5, and 6 with Tests 7 through 11.

5.3.3.3 Tire Fire Extinguishment

When the overhead nozzles were turned off at the end of 3 minutes, fires similar to those depicted in Figures 5.13 and 5.14 continued on each tire and the JP5 in contact with the rubber. These localized fires were treated as described in Section 5.2.4. First the shielded JP5 was extinguished with AFFF generated with the Batel nozzle then various agents were applied to the tires. Water, AFFF, High-Expansion foam, and PKP all readily suppressed the flames; however, application had to continue until the rubber cooled or the glowing combustion under the char layer would rekindle the flames. From the cooling standpoint water and AFFF are essentially equal; however, care must be exercised with water not to wash away the protective foam layer or splash fuel onto the tire fire. High expansion foam was quite effective when it reached the fire but for the modest head attainable with the 4 foot high screen wire fence and the close spacings between and under the vehicles the foam began to escape over the fence, as observed in Figure 5.6(d), before reaching the back tires or filling the space under the trucks. Better confinement is obviously required with High-Expansion foam. PKP was applied to some of the smaller fires involving single tires. The flames were readily extinguished but it becomes a very tedious process to prevent reignition.

Since several agents are satisfactory the main problem is the mode of application and this problem is compounded by the narrow isles between trucks. In one case all of the tires at adjacent positions on two trucks went flat during the fire causing the bodies to tilt and make contact thereby further reducing the access. These fires were not enclosed; consequently, the heat and smoke escaped but in a ship's hold the insult from these combustion products becomes a serious obstacle during mop-up operations. If only one or two vehicles are involved, manual extinguishment with hand lines is feasible but a more remote procedure would be desirable with many vehicles. With an all purpose fog-straight stream nozzle on a 1 1/2 inch line, considerable difficulty was encountered in applying water between dual tires and to the back side of the inner tire because of the limited space.

A standard applicator also was difficult to deploy because of the large bend and leg length. A modified short bend applicator for a 1 inch hard line (Figure 5.15) was more convenient and would fit between the duals and the fender, but coverage around the tire's circumference was restricted because of the limited maneuvering space in the narrow isle. Direct impingement is desirable for char penetration and suppression of the glowing combustion. In long burns, or after several tests, when the fire burns through the casing and combustion occurs inside the tire, extinguishment becomes increasingly difficult. By the end of the test series many of the tires were in this burned through condition.

5.3.4 Damage to Aircraft and Vehicles

In accord with the observations of Sections 3.3 and 3.4, the damage to objects in the fire depends on the time, degree of exposure, and the material involved. Flammable materials such as cellulose, rubber, and plastics survived short fires such as Test 4 with little damage when they were shielded from the flames by the steel truck bed. For example, Figure 5.16(a) shows a scorched but usable piece of rope protected only by a shallow ledge and brace; (b) canvas, rope, and other litter in the truck bed; (c) upholstery and a plastic steering wheel in the open cab; and (d) rubber fanbelts, hoses, and cables in an open engine compartment. Most of these items did not ignite or were suppressed by the foam before damage occurred. Also much of the paint was undamaged. Incidentally, three of the foam nozzles were damaged during this short fire, two diffuser plates melted off, and parts of one nozzle casting melted. After the fire in Test 5 which had a 5 minute preburn, the destruction of combustible items was fairly complete except for the bigger pieces of wood and the tires. Figures 5.16(e) and (f) show the burned out cab interiors of trucks No. 2 and 1, respectively. The upholstery is burned, low melting point door handles, light covers, etc., have melted and drained away and the windows in the cab have melted. Besides these qualitative observations temperatures were measured in truck No. 1 as described in Section 5.2.2. Table 5.2 lists the maximum temperature reached in the fuel tank, engine oil space, and drive shaft during several tests. Obviously, the heat capacity of the water in the fuel tank kept that temperature within safe limits. Presumably gasoline with a specific heat, .6, that of water, would only reach 225°F in the longest fire;

i.e., Test 5. Unfortunately, the temperature measurements were not entirely satisfactory as indicated by the number of blank or off-scale values. Several factors contributed to these omissions in the data; e.g., dragging the mop-up lines around the truck damaged some of the protective insulation on the thermocouple leads and deformation of the truck as the frame sagged from the heat moved the point of attachment with respect to the lead-in pipe. The longer time from ignition to start of suppression influenced the temperatures recorded for Tests 5 and 7 but is not reflected in Test 15. As in Section 3.3 the aluminum aircraft wings suffered catastrophic damage even in the shortest fires. Figure 5.17 shows a wing before and after a short fire; i.e., during the 30 second preburn of Test 10, the wing collapsed into the fuel bed. Complete melting of the skin and small structural members occurred at the wing tips; however, the massize structural members at the hinge end had sufficient heat capacity to survive. The wing in Test 5 instrumented with the copper slug calorimeters to measure the thermal insult exhibited the heating behavior shown in Figure 5.18 for the two thermocouple positions; i.e., temperature versus time. Figure 5.19 shows the corresponding temperatures plotted as a function of the thermal input measured with the calorimeters. As long as heat losses from the wing remain negligible, the temperature versus thermal input curve remains linear. This wing collapsed under its own weight at 323 seconds; however, the temperature plots indicate sufficient heating to anneal and weaken the aluminum within 120 seconds assuming an annealing temperature of 375°F.

5.4 Conclusions from Site 300 Tests

5.4.1 Capabilities of Overhead Foam Sprinkler Systems

The results with full scale vehicles and aircraft wings confirm the conclusions derived with stylized obstacles in 10 foot diameter fires. Namely, the AFFF sprinklers can knock down the flames from a shadowed JP5 pool fire in time to save a steel ship structure but not in time to prevent serious damage to aircraft and vehicles. Attempting to penetrate the fire plume is not an efficient way to deliver foam to the seat of the fire and the foam does not reach and extinguish shielded Class A fuels that extend above the pool fire. Dual truck tires and the spare tires carried under the truck frames are well shadowed, burn readily, and were not controlled by the overhead system. The close packing employed with vehicle stowage makes access very difficult for extinguishing the tire fires with hand lines. Since the control times and application densities for extinguishment were comparable for the 10 and 40 foot tests, it should be possible to test many of the proposed countermeasures on the smaller fires with a fair degree of reliability. Three percent FC-200 is essentially as good as 6 percent concentration for these tests and applications.

5.4.2 Effects of Obstacles on the Fire Characteristics

The burning rates for the open pool fires; i.e., 4.2 to 4.3 mm/minute, are in agreement with numerous other measurements for JP5; however, the values with vehicles present were generally 10 percent lower.

5.4.3 Fire Damage

Aircraft wings melted and collapsed from 1 to 5 minutes after the JP5 pool was ignited. The instrumented wing had received about 1,800 BTU feet^{-2}. Since the fires are turbulent and the heat loading is not uniform throughout the flames, either in time or space, similar objects exhibited various degrees of damage; e.g., a few foam sprinklers melted during almost every run but not in the same locations. Incidentally, the foam sprinklers should be made out of a higher melting point material than the present brass.

The vehicle bodies provided considerable protection to combustible materials during the short preburns. Presumably much of the cargo could survive a similar fire.

6.0 COUNTERMEASURES AND OPTIMUM EXTINGUISHING SYSTEMS

6.1 Criteria for Designing Optimum Extinguishing Systems

The process of optimizing an extinguishing system involves selecting the most favorable or satisfactory combination of performance and cost. Performance can be specified in terms of (1) the systems effect on the fire; e.g., time to control, time to extinguish, limitation on damage; (2) the basic suppression requirements of agent, application density, and application rate; or (3) by the design parameter for a particular type of suppression system such as the type of nozzles, their location and discharge requirements for a foam sprinkling system. This discussion commences with the first alternative, particularly the concept of damage accrued during the suppression period and progresses to the basic suppression requirements. Various possibilities for achieving the required performance are considered in the next section.

If we assume that the degree of damage to aircraft, vehicles, or ships determines the available time for fire control, the time will vary according to the cargo as indicated schematically in Figure 6.0. Judging by the temperatures for aircraft wings in Figure 5.18 and the loss of strength for aluminum alloys heated to about 350 to 400^{o}F, damage in the skin commenced at about 2 minutes after ignition and in the top of the wing frame structure in about 3 1/2 minutes.

Since the time lapse photographs show this wing was not completely surrounded in flames for much of the burn and other wings have melted and collapsed within 1 minute of ignition the damage curve must be broadened to reflect environment.

With the vehicles many of the components were beyond use at the end of the 5 minute preburn while others were not visibly beyond use; therefore, the damage curve would be something like the middle curve. Since none of the data correspond to ship features, that damage curve is even more approximate. Ship components such as cables, electronics, etc., would be damaged easily corresponding to similar damage in the vehicles but the large structural members would survive much longer.

Figure 6.0(b) indicates the trend of extinguishment costs as a function of the control time. Assuming the critical application is reasonably independent of time, discharge rate, and all the associated equipment, the cost will vary inversely with the extinguishment time; i.e., a hyperbolic relationship.

In this overly simplified analysis it is assumed that the minimum extinguishment or control time imposed by foam migration under obstructions can be augmented by additional dispensers or some other cost increasing modifications to the system. Since costs and damage factors exhibit opposite behaviors, the process of optimization involves moving as far to the right on the cost curve as possible before damages become excessive and as far to the left on the damage curve as the costs will permit. Each damage curve in 6.0(a) imposes a different limit on the extinguishment time and cost. For example, fires under aircraft should be contained or extinguished within about 1 minute. Aside from the tires, vehicles, and their more sensitive cargoes are limited to about 2 minutes. The existing overhead sprinkling system does not meet the aircraft requirements but should suffice for the vehicles and ship. If the trucks are loaded with munitions meeting the 5 minute cookoff tests, the extinguishment times with the foam sprinklers should still be adequate provided the tire flames miss the critical cargo. For extinguishment at least 1 gallon of AFFF per 100 feet^2 should be delivered to the surface of a JP5 pool fire during the allotted time.

6.2 Countermeasure Considerations

Fire protection involves vigilance at all steps from prevention through detection and confinement to suppression. While this section focuses on suppression, a few comments about the other areas are pertinent to the choice of agent and technique for extinguishment. First, the protection should be effective for both self inflicted fires and those originating from enemy action. The chief impact of these ignition sources probably involves detection and the rate of fire buildup and spread. Accidental fires are more apt to start smaller and build up slower than their enemy inflicted counterparts; however, detection is usually very prompt in the latter case. Large rapidly developing fires are difficult to control by hand equipment, particularly where access is limited by confinement or obstacles; therefore, the suggestions listed below emphasize suppression equipment and procedures that keep the fireman out of burning compartment. In the construction of new ships, confinement and containment are important factors but only a few such suggestions are considered here. Since satisfactory agents are available for both the liquid fuel and tire fires, we have concentrated on techniques for dispensing the agent to the fire within the allotted time. Opportunities offered by each side of the fire triangle have been considered; e.g., removing the fire oxygen and/or heat.

6.3 Suggestions for Fast Efficient Hangar Deck Fire Extinguishment

The goals here are threefold; (a) improve the application efficiency by minimizing the trajectory through the fire plume,

(b) reduce the extinguishment time and the damage to aircraft by avoiding shadowing effects and the delays required for foam to flow under the obstructions, and (c) enhance the protection from three dimensional fuel fires.

6.3.1 Low Level Peripheral Nozzles Augmenting a Reduced Concentration of Overhead Nozzles

A row of nozzles along the sides of the hangar bay and close to the deck would be in position to minimize plume losses and shadow effects. In a typical parking pattern (Figure 2.0) most of the aircraft are along the outer bulkheads where they would receive partial protection from peripheral nozzles. If a uniform foam layer could be achieved out to a distance of about 25 feet, the peripheral nozzles could protect about half of a conventional hangar deck and all of the hangar area on smaller ships. The main problem will be to apply the foam uniformly. Existing foam nozzles, either stationary or rotating, are not outstanding in this respect. For example, with a rotating nozzle the application rate at every distance from the point of rotation should be proportional to that distance. To minimize the travel through the fire plume, the nozzles should start their application at the bulkhead and sweep the flames out to the limit of the trajectory.

6.3.2 Pop-Up Sprinklers in the Deck (For New Construction)

The flush deck nozzles tested in the CASS series exhibited three characteristic weaknesses; (1) they dispense mostly droplets, very little foam; consequently, the agent does not arrive at the fuel surface in the most effective physical state; (2) it is difficult to achieve a uniform application density simultaneously with a low trajectory; and (3) plugging with various types of debris remains a continuing problem. More flexibility and efficiency can be achieved in foam generation and trajectory with larger nozzles that pop-up above the deck during operation. Also the plugging problem could be alleviated with a cap on top of the nozzle to form a flush closure when not in use.

6.3.3 Nursing Aircraft

With undamaged aircraft a set of nozzles on the underside of the aircraft would be in a good position to provide protection from pool fires. To avoid unnecessary weight, the nozzles and piping should be incorporated as part of the structural supports in new aircraft or bomb racks on new or old aircraft so the material will serve a dual purpose. When parked, the plane would be attached by an umbilical cord to the foam supply line in the bulkhead or deck. Actuation could be either automatic or from the conflagration station. This equipment also would provide additional protection on the flight deck, particularly in unsprinkled areas.

6.3.4 Fire Fighting Hitching Posts

A similar approach would combine foam dispensing nozzles and tie down fixtures. As envisioned tie down points in the parking area also would be ports to the foam supply line. After the plane was parked, a foam dispensing tie down anchor would be plugged into the port and cables would be attached to the aircraft in the usual manner. Again the foam lines could be part of the ship's structural framework to avoid extra weight.

6.3.5 Self-Contained Sentinels

Pressurized self-contained dispensers for AFFF, Halon, powder, or high expansion foam can be substituted for the hitching posts or bulkhead dispensers. Activation could be by thermally triggered valves. Such devices have been suggested in the past for protection when ships are in port or undergoing overhaul and many compartments are unmanned. These dispensers are commercially available for Halon 1301 and could readily be adapted to AFFF or powder.

6.4 Spilled Fuel Control

Another approach to hangar deck safety is to minimize the potential fire hazard through control of the spilling fuel. Several possibilities are (1) confine the fuel to a small area in order to minimize the fire size, (2) remove the fuel through suitable drains, and/or (3) reduce the burning rate by interrupting the fuel surface with noncombustible material. Honeycomb deck structures offer an approach to all three modes of fuel control.

6.5 Coping with the Tire Fire Problem on Stowed Vehicles

White several agents satisfactorily extinguished tire fires in the full scale tests, there are serious problems with the application techniques. In this section we consider first the tested agents and techniques then speculate about other possibilities.

6.5.1 Water in Various Forms - Plain, Emulsified, Low Expansion Foam, High Expansion Foam

The cooling action of plain water was very effective in permanently extinguishing tire fires when it could be applied directly to the seat of the fire. Aboard ship, handlines could be used with difficulty if only a few tires are involved and the heat and smoke permit access. Generally, accidental fires would start smaller than the Site 300 test fires and under prompt discovery would be attacked with handlines; however, the fires resulting from enemy action could easily be large enough to cause serious difficulty with the handline approach. With AFFF, the application problem is the same as with plain water except for the advantage in protecting spilled liquid fuels.

Several factors complicate applying the water or AFFF remotely. First the number and types of vehicles change from trip to trip; therefore, there is no consistent parking pattern as would be required to use deck sprinklers effectively. Second the lower framework and obstructions under the truck would prevent the successful use of moderate range nozzles mounted low in the bulkhead. Third, the value of a truck is modest compared to aircraft; therefore, built-in applications to be used with umbilical cords, etc., are more difficult to justify but could be effective and quick to extinguish this difficult area. Similar problems arise with the sentinel system.

High expansion foam made with fresh water and air extinguished some of the tires and is suitable for remote application but again there are some complications. On some of the ships, vehicles are stowed several decks below the weather deck; consequently, the available air may be too hot and/or dirty to make good foam. If the high expansion foam is used after the liquid fuel fire has been controlled with AFFF, the threats from heat and foam destroying combustion products would be reduced and foam might be satisfactorily produced either in the fire compartment or with air from an adjoining compartment. This procedure calls for a dual installation unless a single nozzle could be used for both low and high expansion foam.

Emulsions or "sticky water" were not tested but they should be as effective as water. However, the application problem would be as difficult, if not more so, as for plain water.

A positive factor that applies to all of the water techniques is that holes in the compartment resulting from enemy action would not prevent the technique from functioning provided sufficient agent pipes remained effective.

6.5.2 Gases and Vapors; e.g., N_2, CO_2, Halons, Steam

Since these agents were not examined we can only speculate about these pros and cons. First, all are ideal for remote operation by total flooding; therefore, there is not a problem of reaching the seat of the fire. Presumably any shadowing effects are minimal and the agent can reach all areas very quickly. Second, these agents are effective in extinguishing flames from both the liquid pool and the tires; consequently, one system will suffice. Third, there may be some complications because of the glowing ignition and char in a well developed tire fire. These gases and vapors are not particularly effective cooling agents; therefore, the quenching atmosphere will have to be maintained until the tires cool. While we do not have the concentrations required to control glowing combustion in rubber, the results with other glowing combustion fires suggest substantially higher values will be required than for the liquid fuels. Substantial holes due to enemy action could complicate achieving and maintaining the required agent concentration.

6.5.3 Powders - PKP, Monnex, etc. - Ammonium Dihydrogen Phosphate

The powders fall between (1) the gases and vapors and (2) water AFFF droplets in inability to reach the concealed fire. A powder cloud has good diffusion capabilities but the particles escape from the flame zone and settle out before the tires cool and glowing combustion ceases. The alternate practice of applying a layer of Class ABC powder to the char surface appears to be too difficult to be practical.

6.6 Recommendations for Phase II "Exploration of Remedial Measures"

The remedial measures commensurate with the support planned for the Phase II program are limited to applications of existing techniques and equipment where only minor installation modifications are required. Two types of action are contemplated in the following list: (1) testing some existing application equipment and agents and (2) thinking about some of the more remote possibilities.

6.6.1 Testing Effort

6.6.1.1 Test Nozzles Suitable for "Low Level Peripheral Protection of Hangar Decks"

6.6.1.2 Determine Concentrations of N_2 or Halon 1301 to Extinguish Glowing Combustion in Rubber and the Feasibility of Dispensing the Agent Through Existing Sprinkler Systems

6.6.1.3 Examine Nozzles Potentially Capable of Dispensing both AFFF and High Expansion Foam

6.6.2 Exploratory Effort

6.6.2.1 Examine Concept of "Nursing Aircraft" in More Detail

6.6.2.2 Explore Potential for Coating or Modifying Rubber to Reduce Flammability Hazard

6.6.2.3 Consider Deck Designs for Confining or Controlling Spilled Fuel

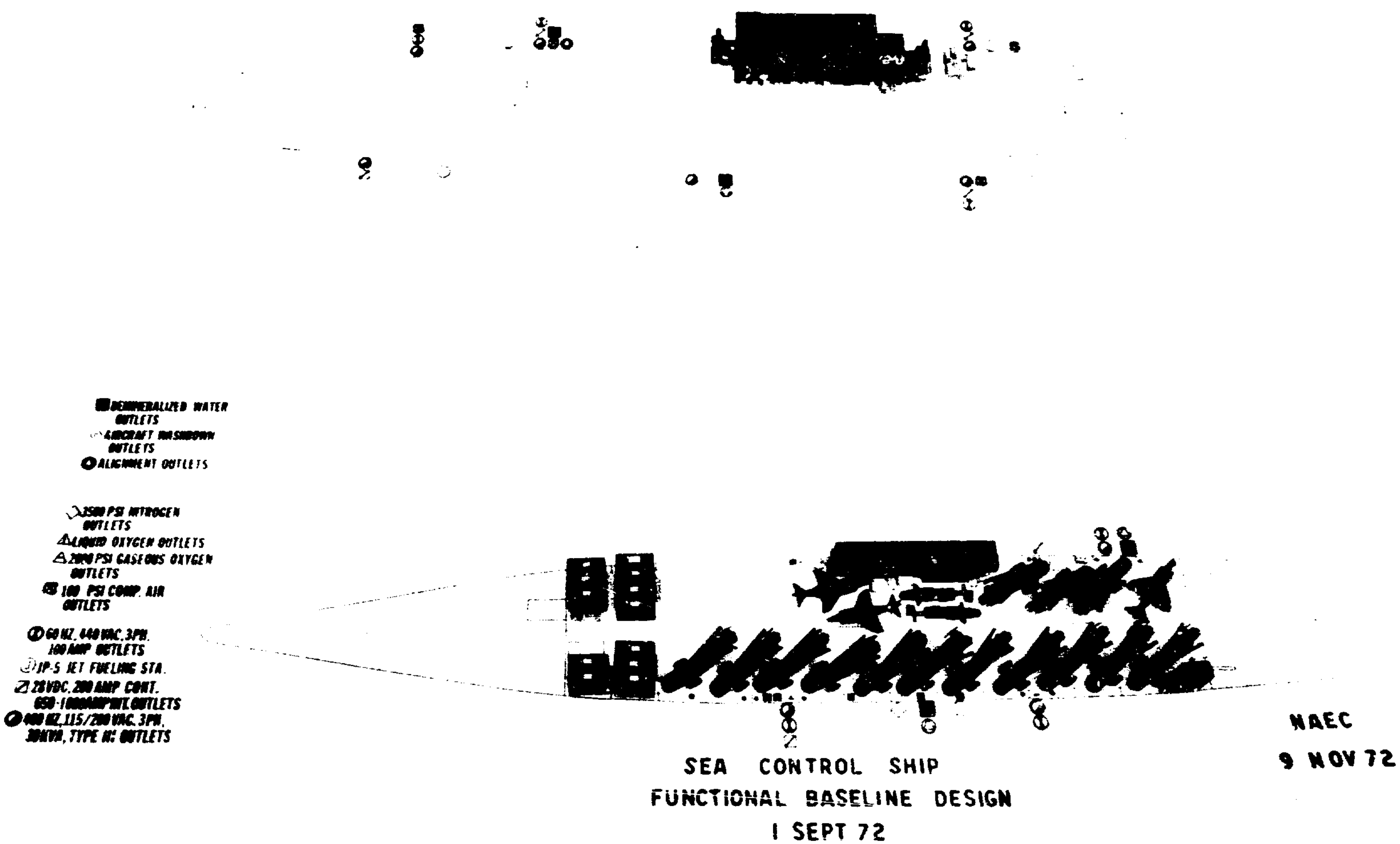
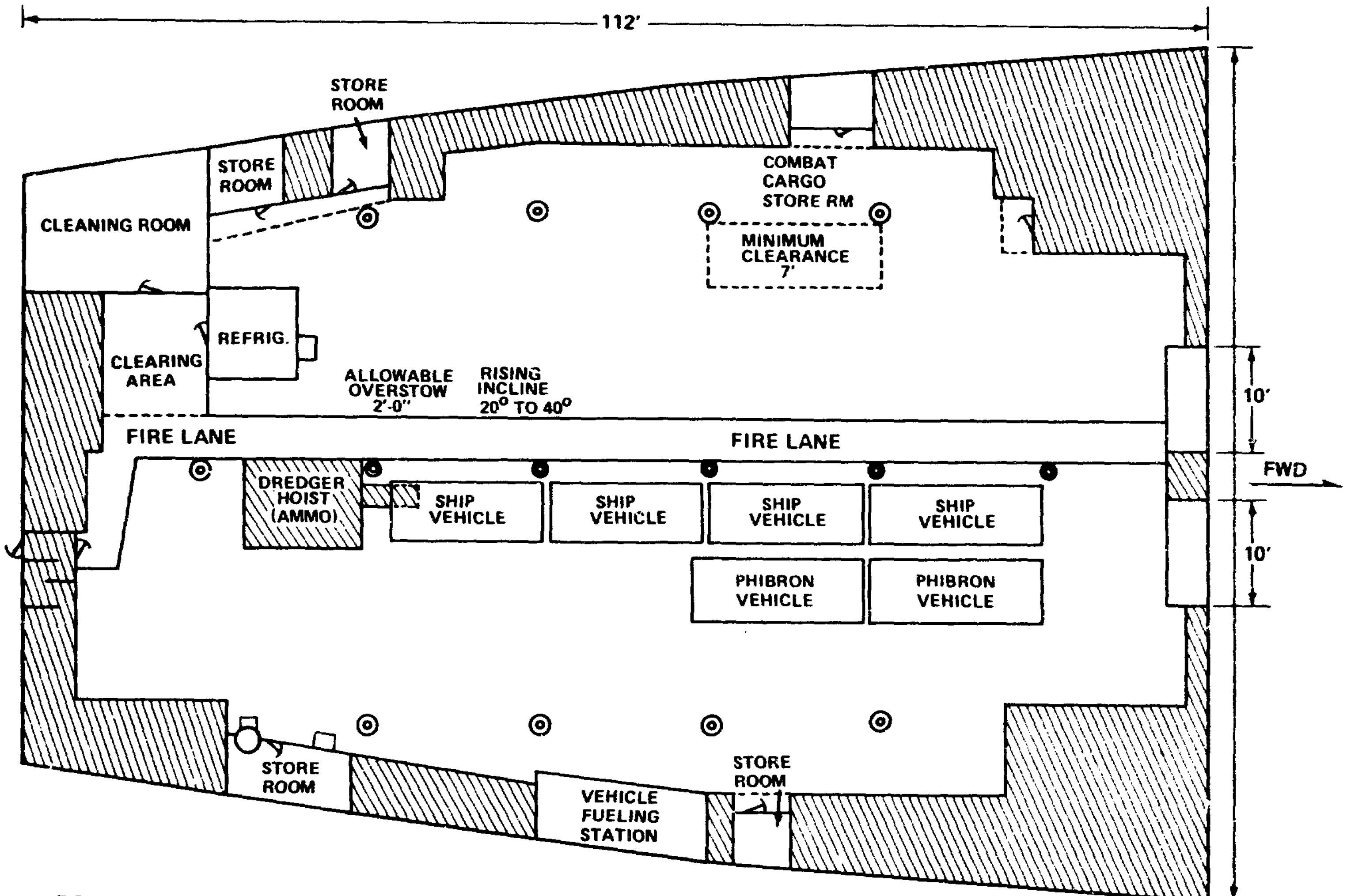


FIG. 2.0 SEA CONTROL SHIP FUNCTIONAL BASELINE DESIGN, 1 SEP 72



DOOR OPENING 10' x 10'
SQUARE FEET 4, 646
MINMUM CLEARANCE 8'-7"
(EXCEPT AS NOTED)

SCALE: 1/8" = 1.0"

NOTE: LEAVE SPACE FOR SHIP/PHIBRON VEHICLES. VEHICLES MAY BE ADJUSTED LATERALLY SO LONG AS THEY REMAIN IN FRONT OF DOORS AND A MINIMUM OF A 4 FT. WIDE FIRE LANE IS MAINTAINED IN FRONT OF PORT V.S. DOOR AND EXTENDING THE LENGTH OF THE SPACE.

FIG. 2.1 MAIN DECK (AFT) VEHICLE STOWAGE (1-111-0-A) USS NEW ORLEANS (LPH-11).

USS MOBILE
LKA-115
SLCP CH 1

CARGO BOOMS			
HOLD	15T	40T	70T*
1	2	1	1
2	2		1
3	2	1	1
4	2		1

* THERE ARE TWO 70T BOOMS - ONE WORKING HOLD 1 OR 2 AND THE OTHER WORKING HOLD 3 OR 4.

ABBREVIATION CODES

DC	DEBARKATION CONTROL
PH	PILOT HOUSE (BRIDGE)
CIC	COMBAT INFORMATION CENTER
SS	SHIPS STORE (PX)
BS	BARBER SHOP
CCO	COMBAT CARGO OFFICE
SC	SPECIAL CARGO SPACES
FBDS	FORWARD BATTLE DRESSING STATION
MBDS	MAIN BATTLE DRESSING STATION
ABDS	AFT BATTLE DRESSING STATION

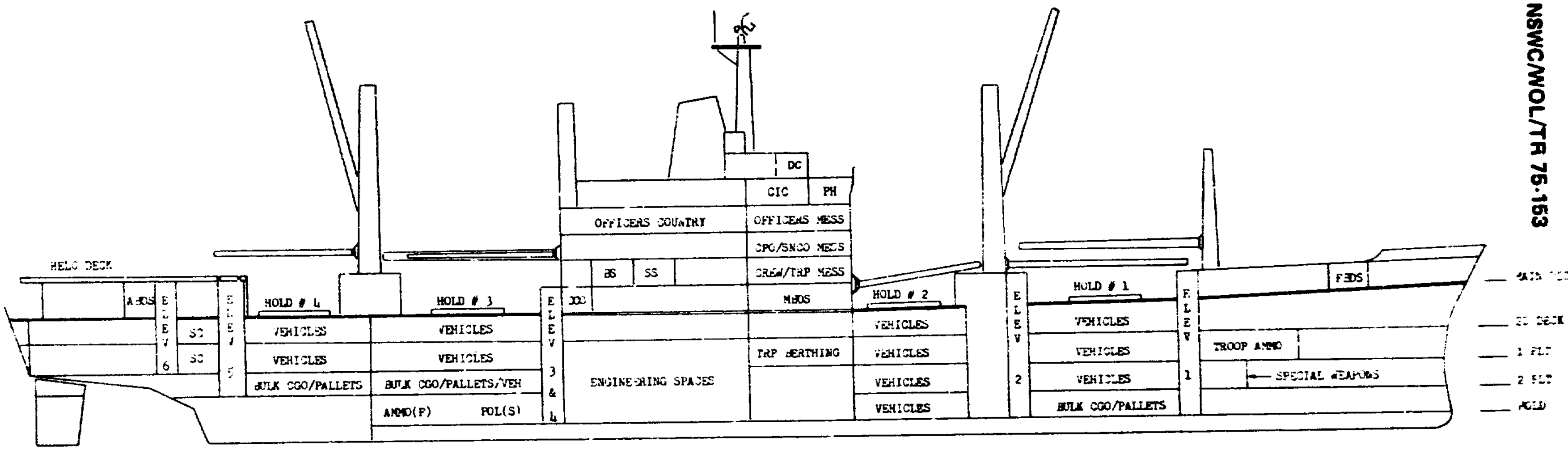
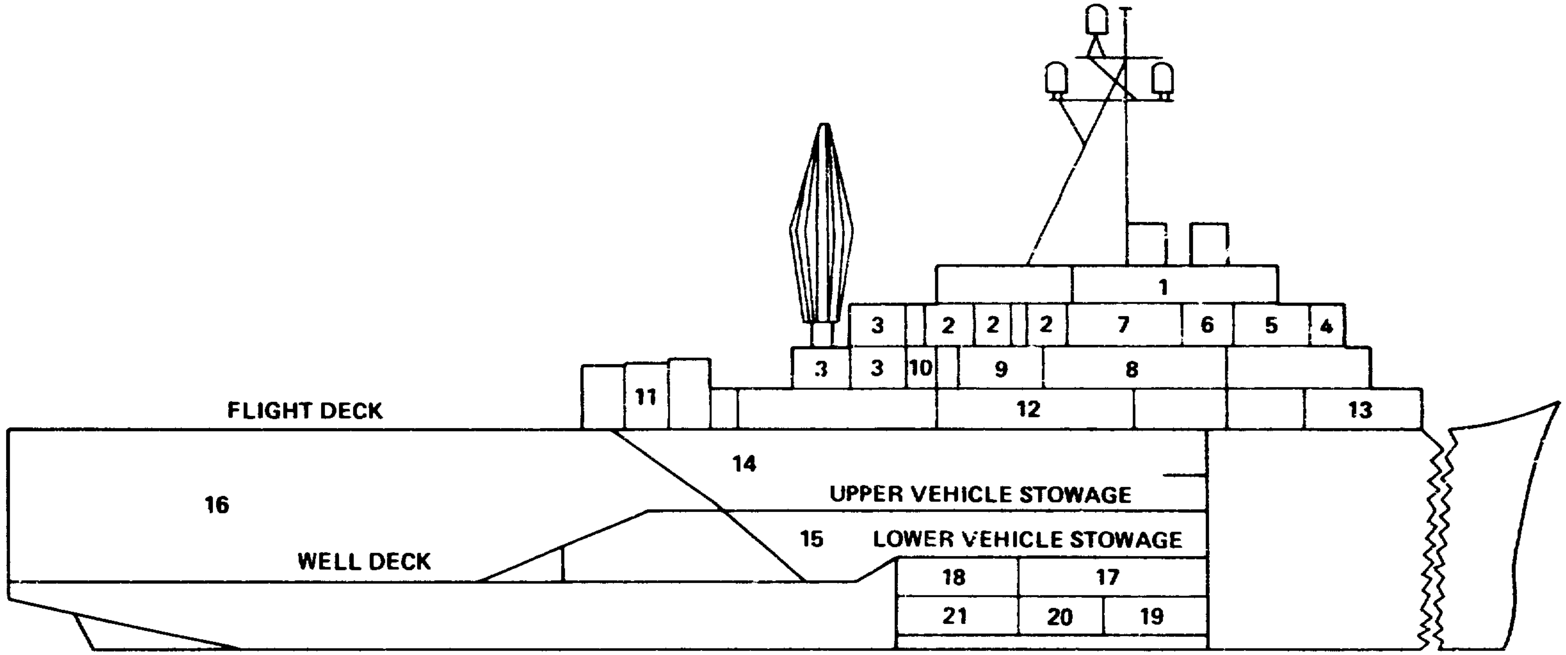


FIG. 2.2 USS MOBILE, LKA-115 SLCP CH 1



1. COMBAT INFORMATION CENTER
2. FLAG OFFICER BILLETING
3. TROOP OFFICER BILLETING
4. FLAG BRIDGE
5. FLAG PLOT
6. SACC
7. TROOP OPERATIONS & MESSAGE CENTERS
8. WARDROOM
9. WARDROOM LOUNGE
10. TROOP C.O. CABIN
11. HANGAR
12. CREW & TROOP MESS
13. CPO MESS & LOUNGE
14. UPPER VEHICLE RAMP
15. LOWER VEHICLE RAMP
16. WATER BARRIER
17. TROOP CARGO & AMMO STOWAGE, 1st PLAT, FWD.
18. TROOP CARGO & AMMO STOWAGE, 1st PLAT, AFT.
19. SPECIAL WEAPONS MAGAZINE
20. TROOP CARGO & AMMO STOWAGE, 2nd PLAT, FWD.
21. TROOP CARGO & AMMO STOWAGE, 2nd PLAT, AFT.

FIG. 2.3 INBOARD PROFILE

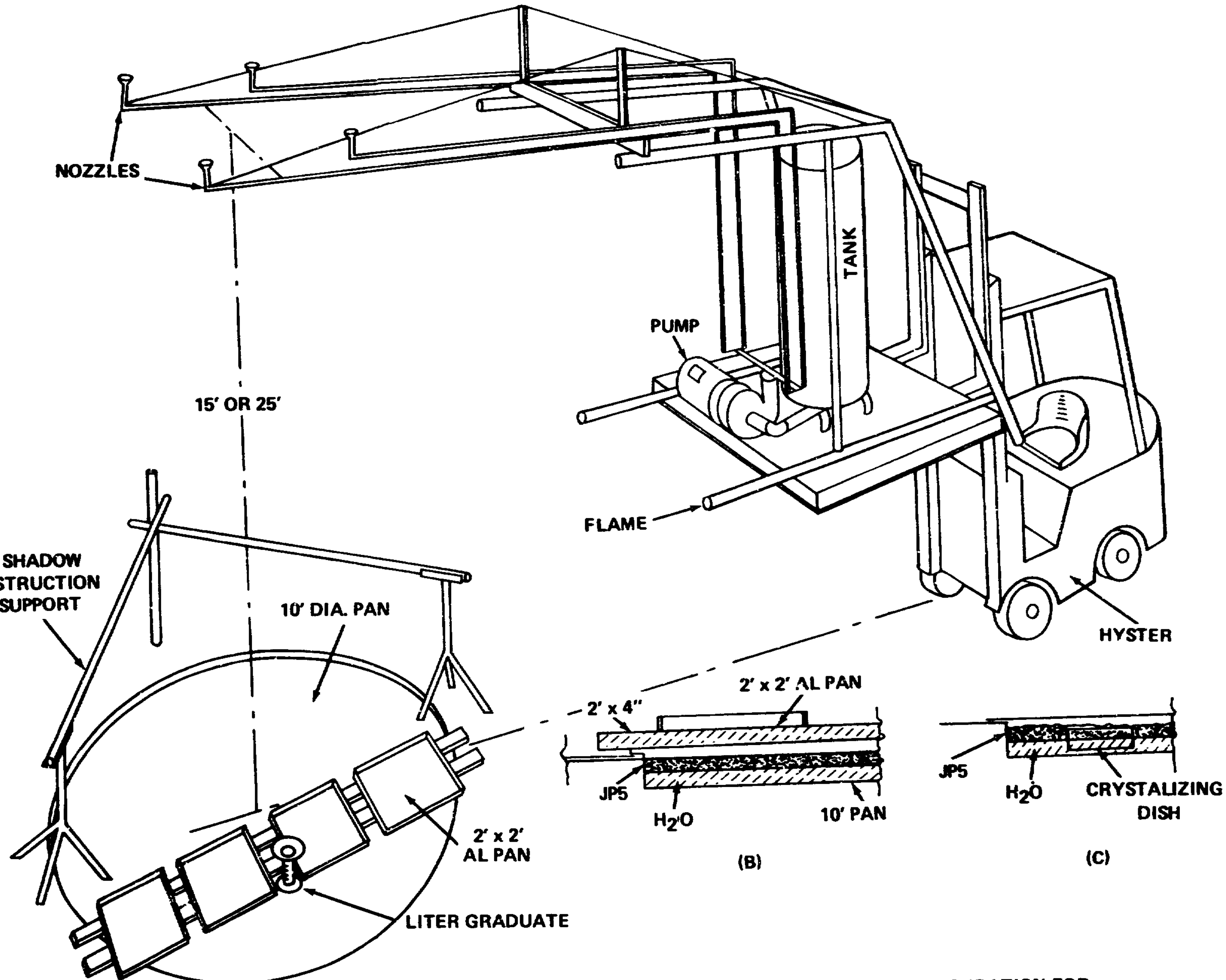
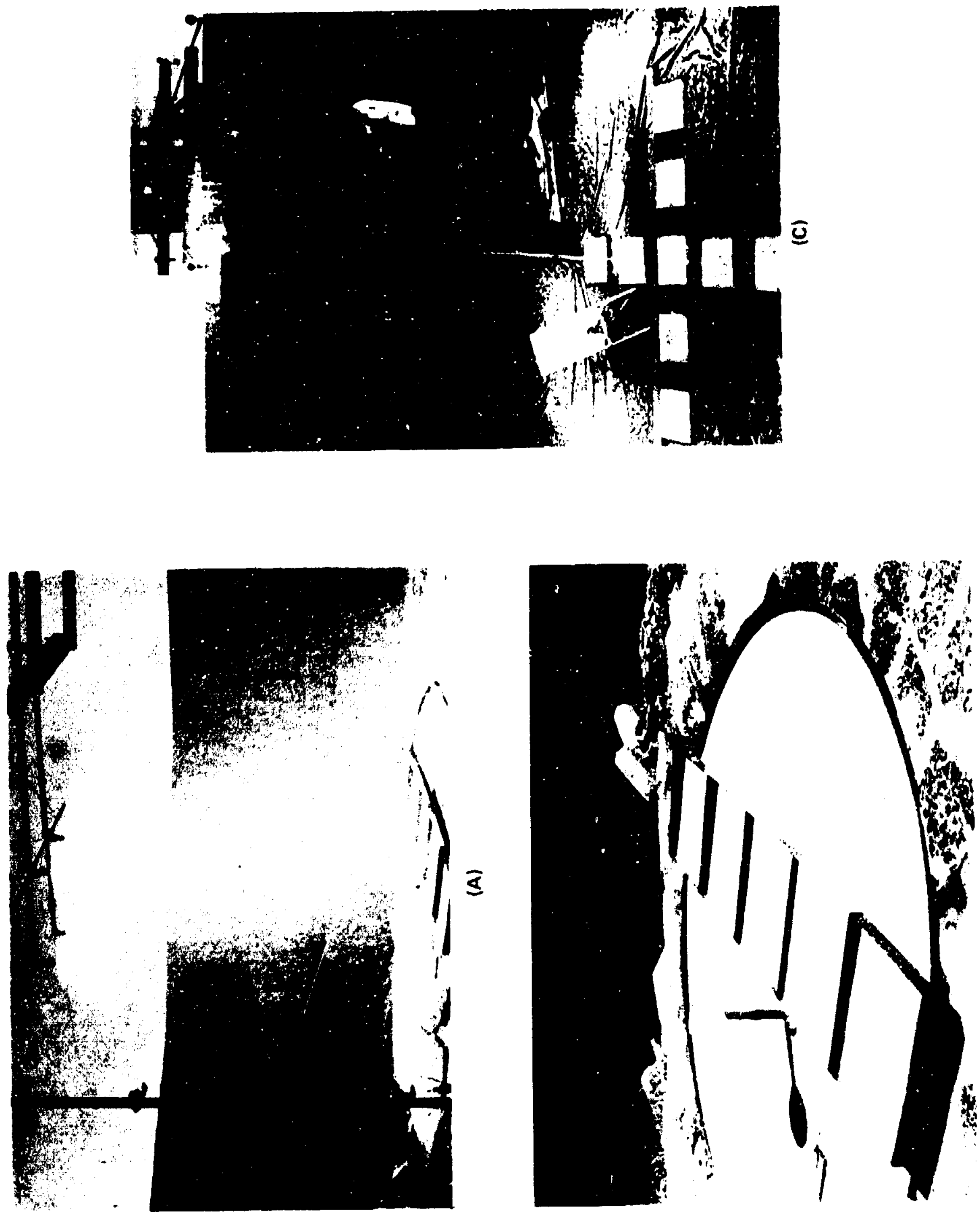


FIG. 3.0 GENERAL EXPERIMENTAL ARRANGEMENT OF FIRE BED AND NOZZLES IN CONFIGURATION FOR MEASURING THE APPLICATION RATE.



(A) (B) (C)

FIG. 3.1 MEASUREMENTS OF FOAM PATTERN, QUALITY AND APPLICATION DENSITY.

D1, 2, 3, 4, 5 = CRYSTALIZING DISHES
R1, 2, 3 = RADIOMETERS
T.C.1, 2, 3 = THERMOCOUPLES
S.P. = GRAVITY STOOL PIGEON
AL = ALUMINUM A/C TAIL SECTION
FE = STEEL SHADOW SHIELD

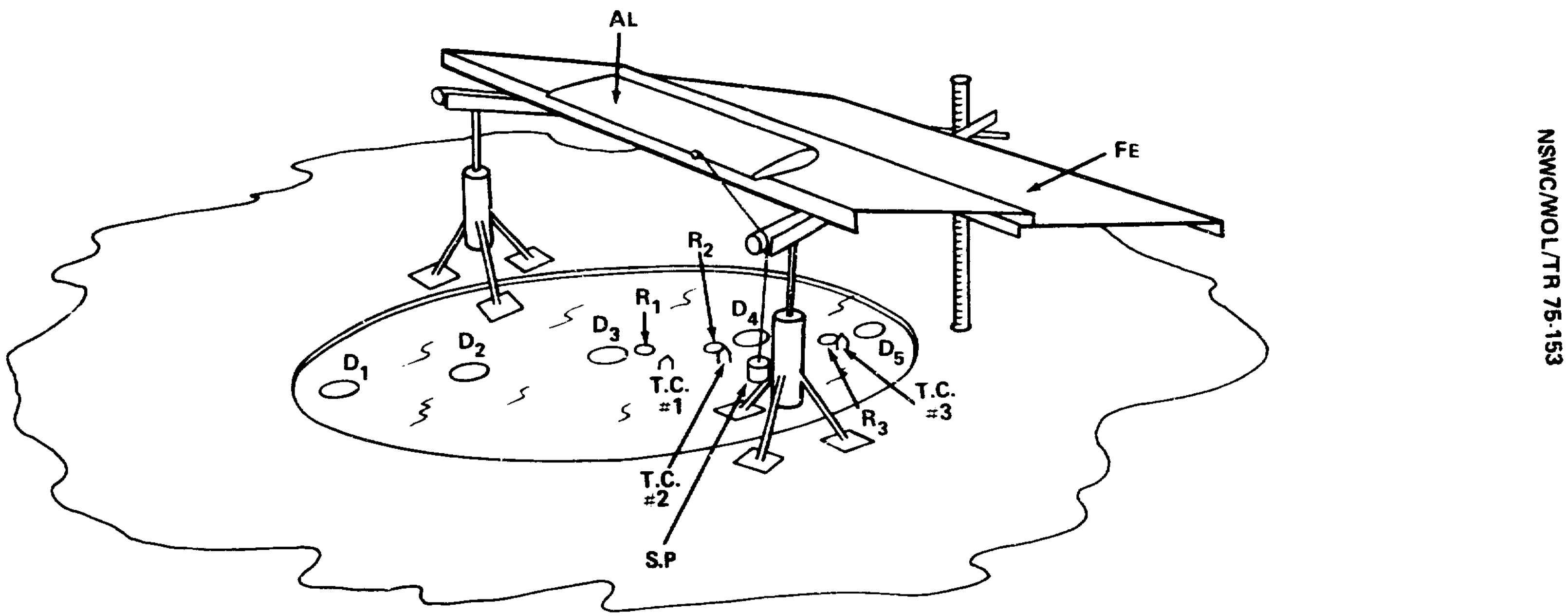


FIG. 3.2 PIPE FRAMEWORK AND SHADOWING OBSTRUCTION.

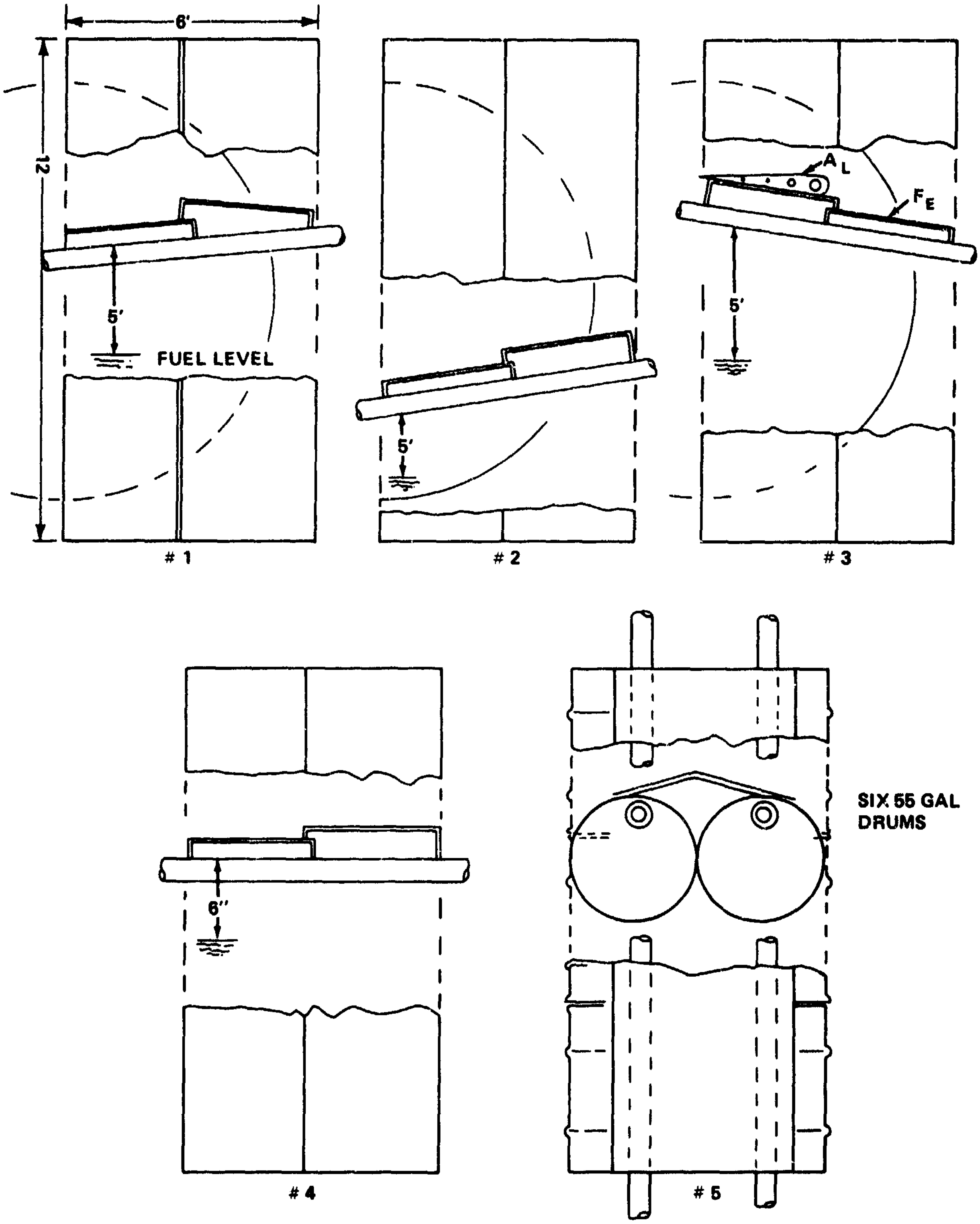


FIG. 3.3 PLAN VIEWS, CROSS SECTIONS AND DESIGNATIONS OF SHADOWING OBSTRUCTIONS.

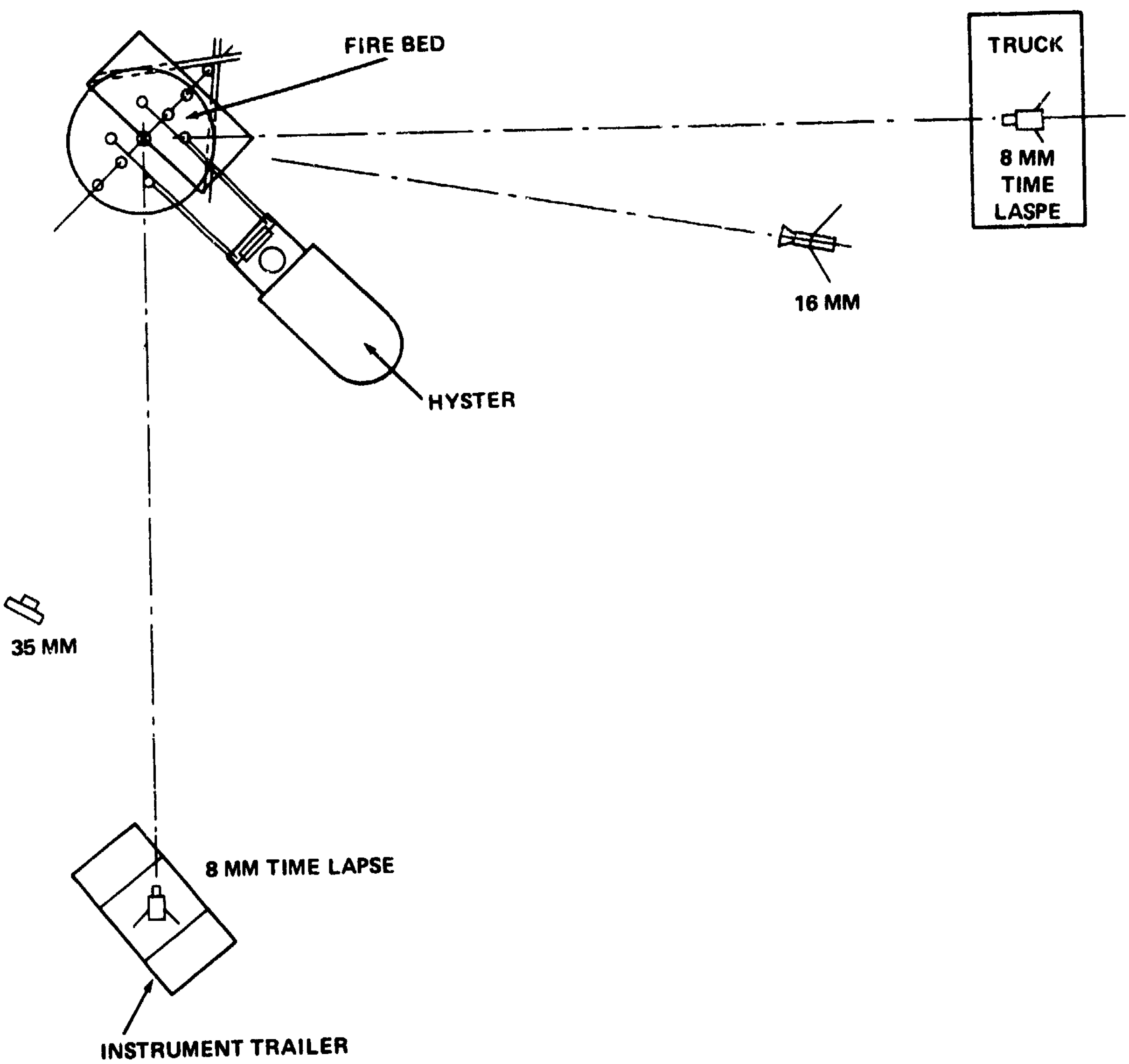
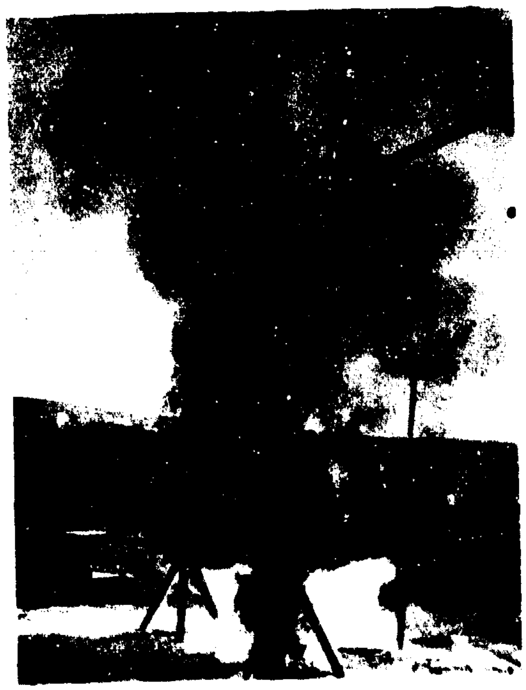


FIG. 3.4 CAMERA COVERAGE AND INSTRUMENT ARRANGEMENT FOR SUPPRESSION TEST IN 10' PAN.

(A)

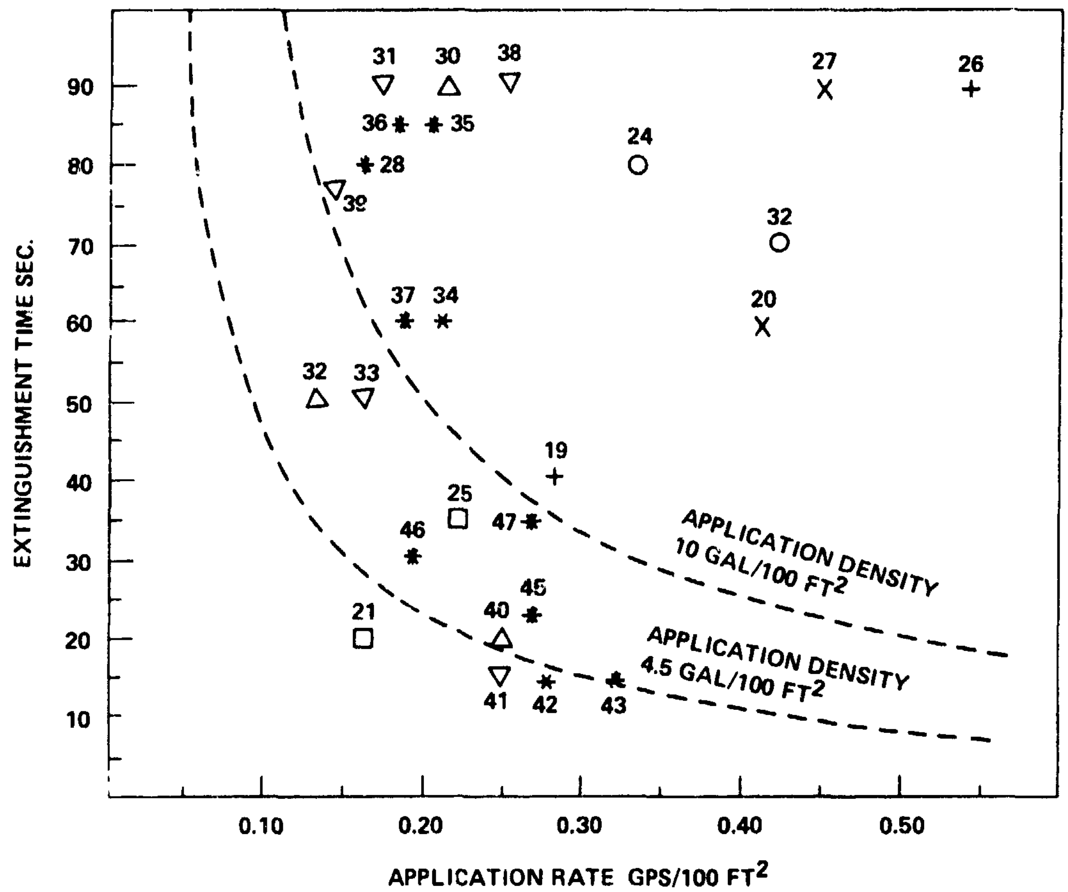
(B)

(C)



(D)

FIG. 3.5 EXTINGUISHMENT OF JP5 FIRE UNDER SIMULATED AIRCRAFT WING, i.e. TYPE 3 OBSTRUCTION TEST 26 (A) FIRE JUST BEFORE ONSET OF SUPPRESSION, (B) FIRE PERIPHERY EXTINGUISHED (C) ONLY SHADOWED AREA BURNING (D) JUST BEFORE COMPLETE EXTINGUISHMENT.



SYMBOLS INDICATE COMBINATIONS OF NOZZLE TYPE HEIGHT AND SPACING

X = 15' HIGH 30" SPACING
✱ = 15' HIGH 8' SPACING
+ = 25' HIGH 30" SPACING
⁎ = 25' HIGH 8' SPACING
□ = 15' HIGH 30" SPACING
▽ = 15' HIGH 8' SPACING
○ = 25' HIGH 30" SPACING
△ = 25' HIGH 8' SPACING

FIG. 3.6 DISCHARGE TIME FOR EXTINGUISHMENT PLOTTED AS A FUNCTION OF THE APPLICATION RATE .

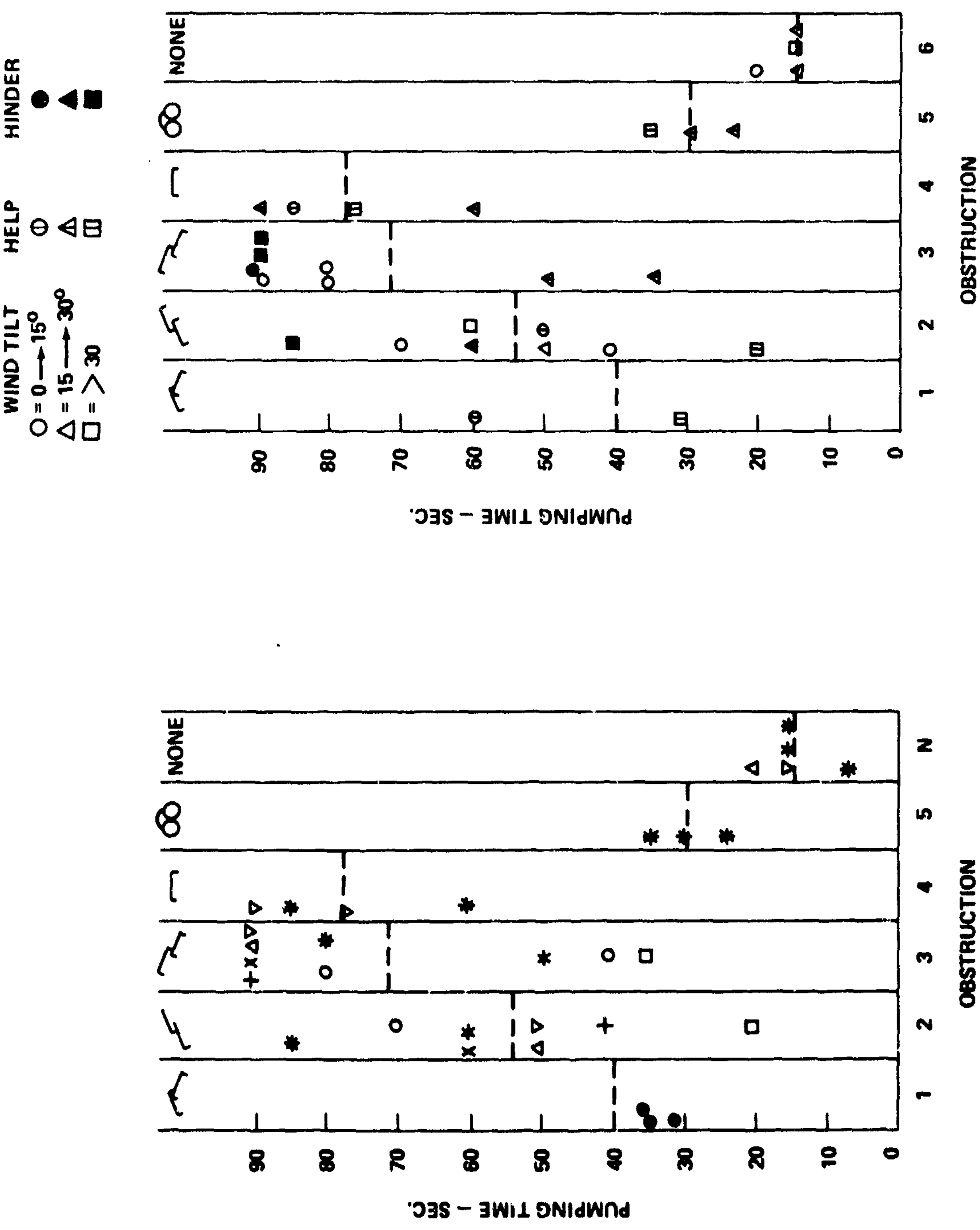


FIG. 3.7 EFFECT OF OBSTRUCTIONS AND WIND ON THE EXTINGUISHMENT TIME.

(A)

(B)

(C)

(D)

FIG. 3.8 EXTINGUISHMENT OF JP5 FIRE UNDER SIMULATED AIRCRAFT FUSELAGE, i.e. TYPE 5 OBSTRUCTION TEST 47; (A) ONSET OF SUPPRESSION, (B) PERIPHERAL FIRE EXTINGUISHED, (C) FIRE BURNING ONLY OVER SIMULATED DECK, (D) WARPED STEEL EXPOSED AFTER FIRE IS OUT.

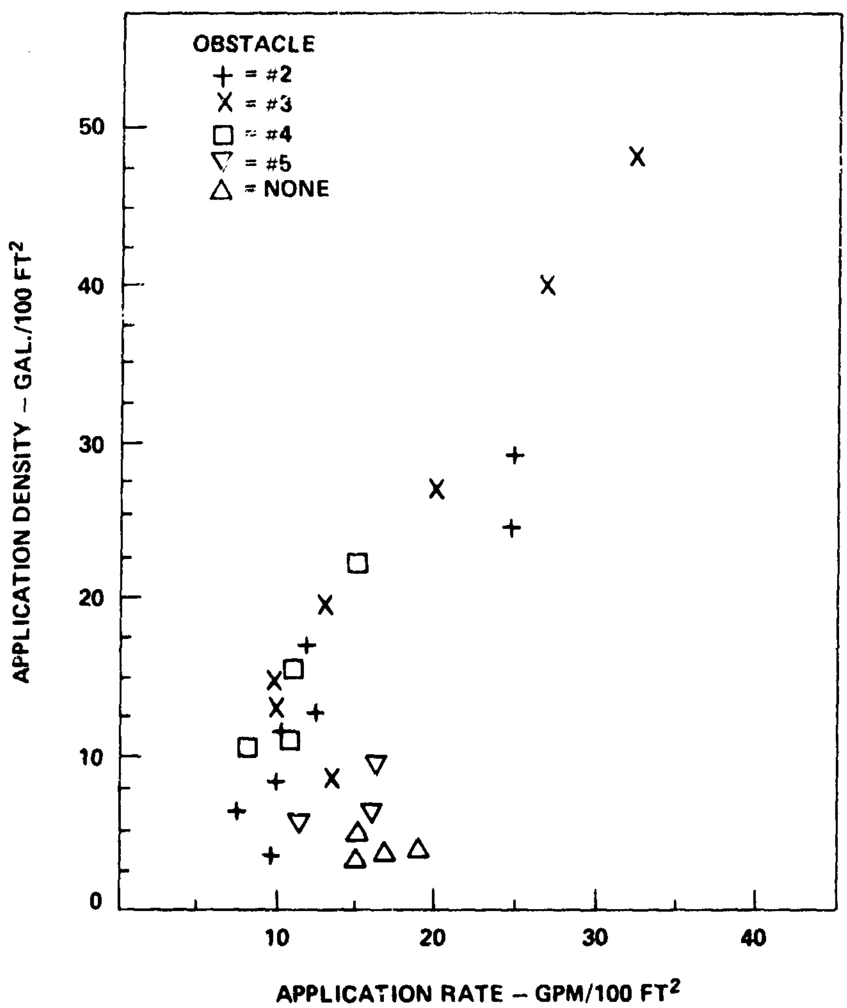


FIG. 3.9 EFFECT OF APPLICATION RATE ON THE EXTINGUISHMENT APPLICATION DENSITY.

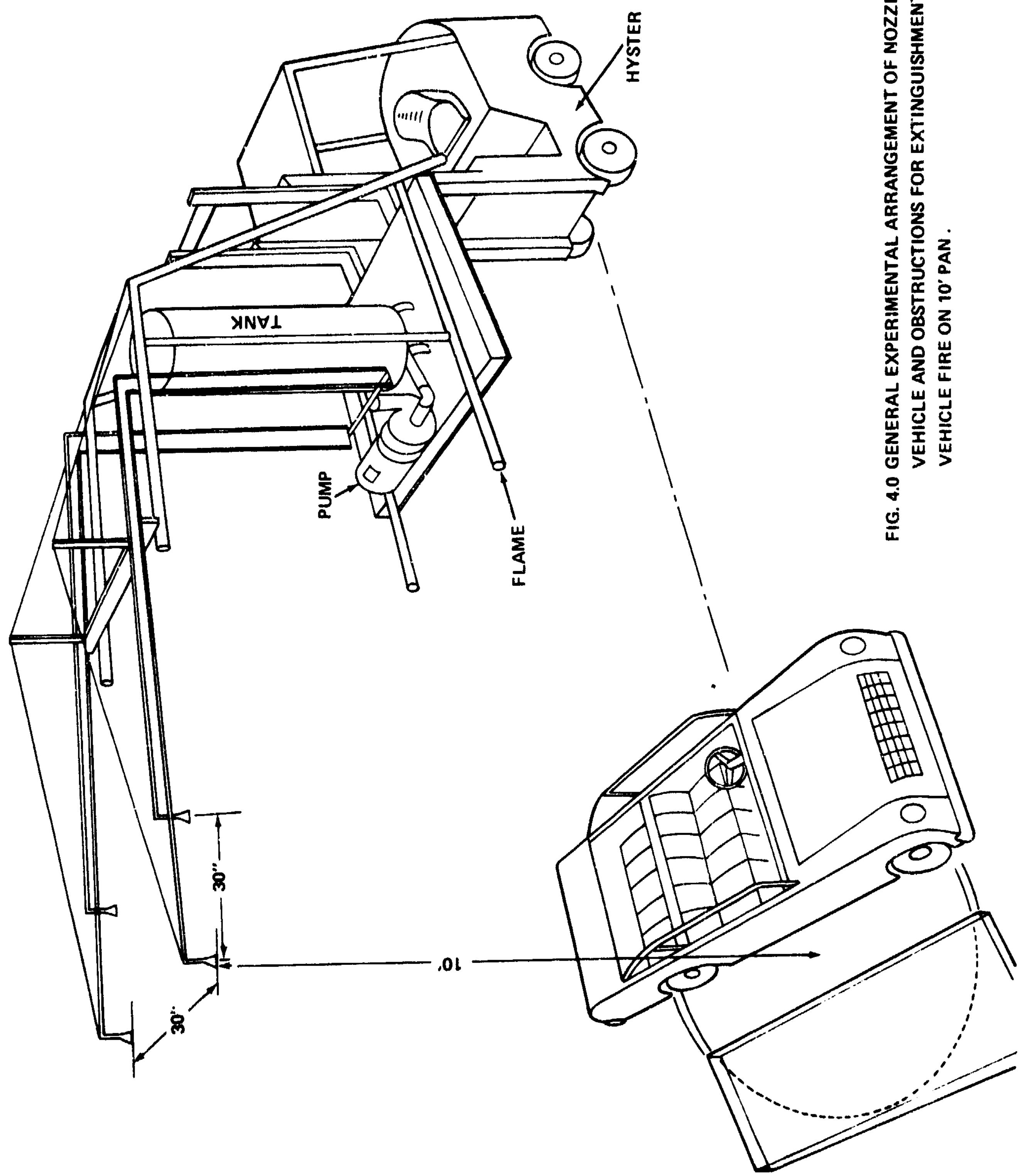
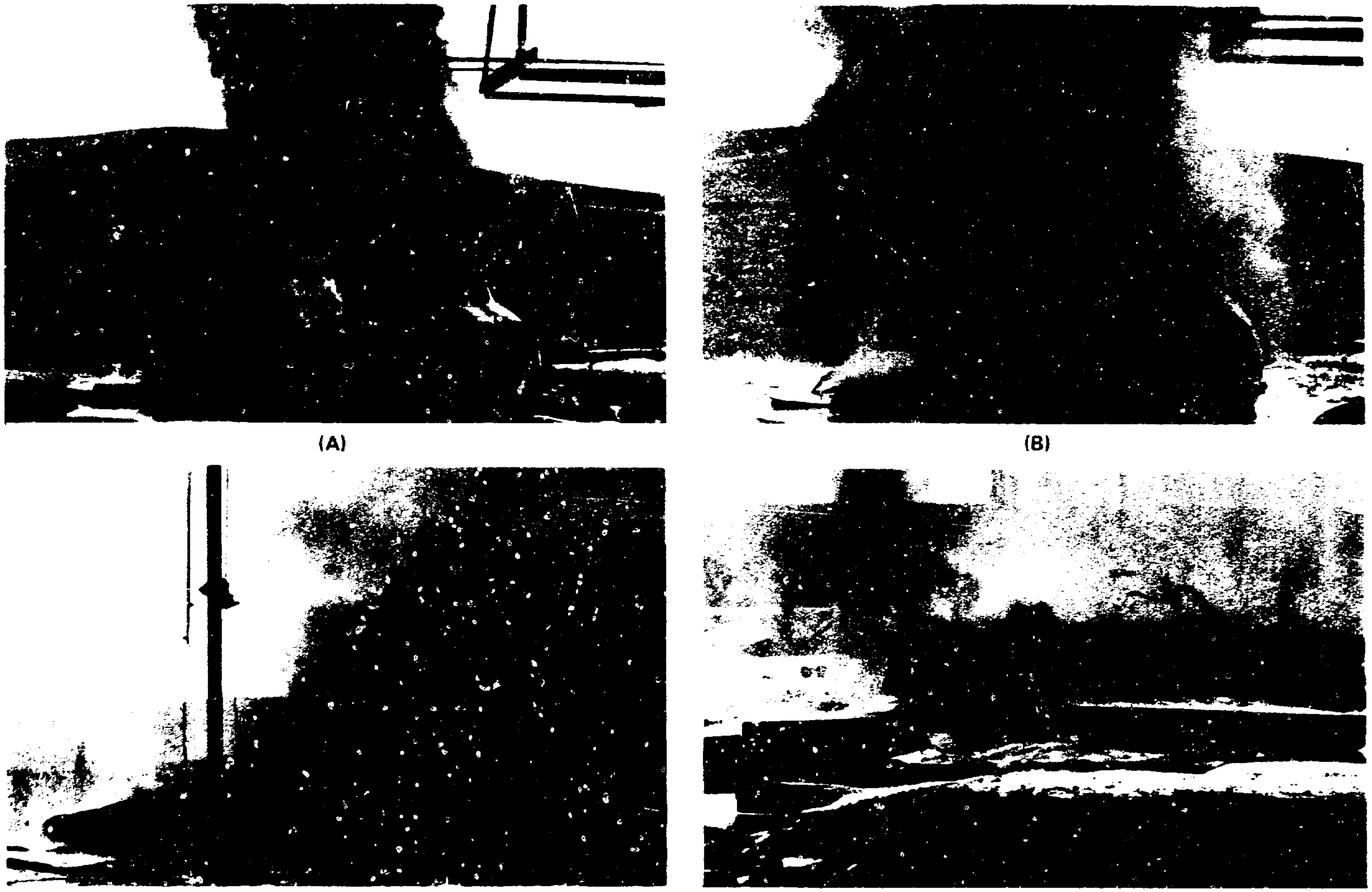


FIG. 4.0 GENERAL EXPERIMENTAL ARRANGEMENT OF NOZZLES, VEHICLE AND OBSTRUCTIONS FOR EXTINGUISHMENT OF VEHICLE FIRE ON 10' PAN.



(A) (B) (C) (D)

FIG. 4.1 EXTINGUISHMENT OF JP5 UNDER A BURNING VEHICLE TEST 50: (A) FIRE DURING PREBURN PERIOD, (B) EARLY STAGE IN SUPPRESSION, (C) JP5 FIRE NEARLY EXTINGUISHED, (D) TIRES PROTECTED BY FENDERS CONTINUE TO BURN.

FIG. 5.0 FIRE BED AT SITE 300 WITH TWO TRUCKS IN POSITION UNDER THE FOAM NOZZLES JUST BEFORE TEST.

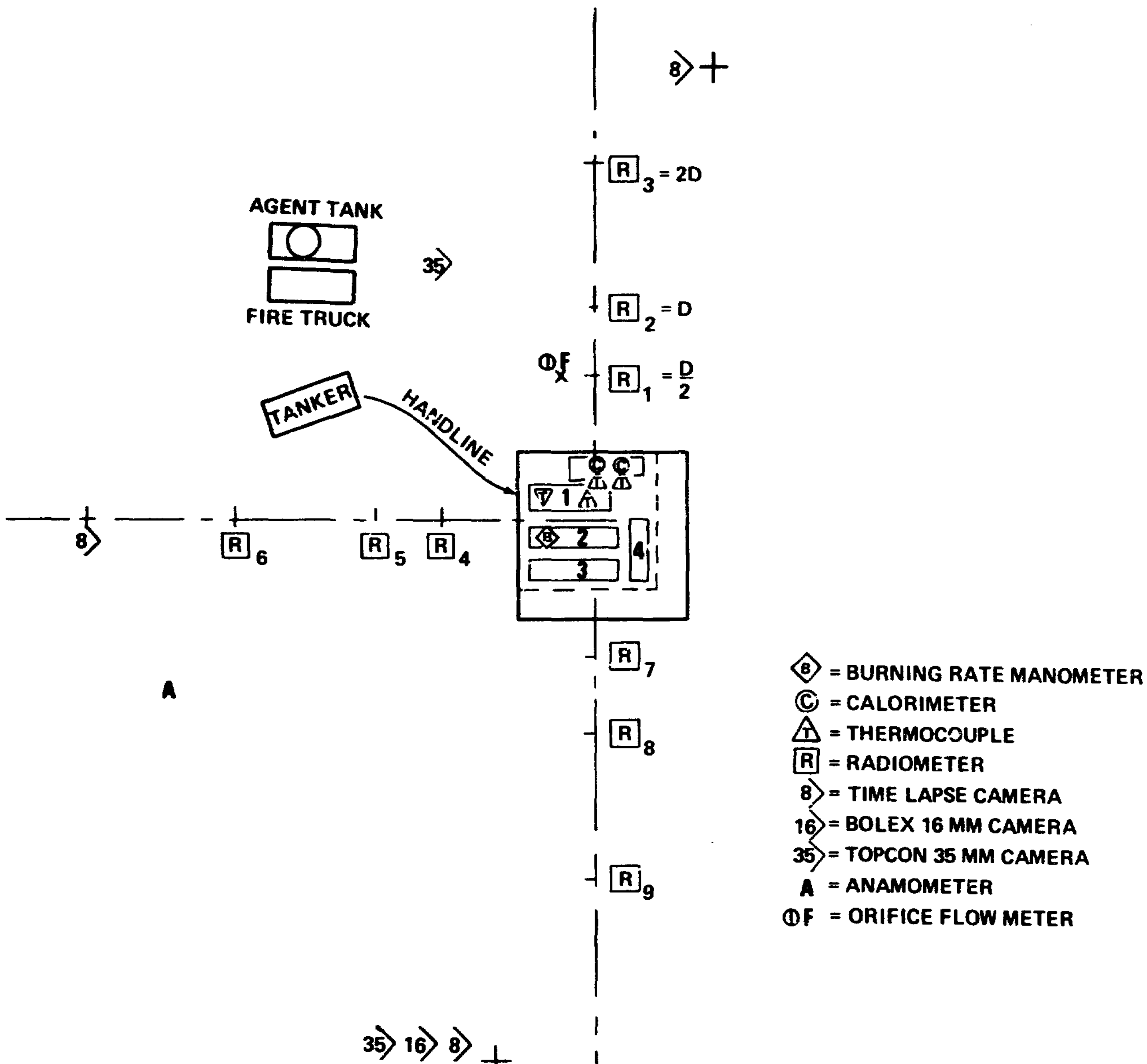
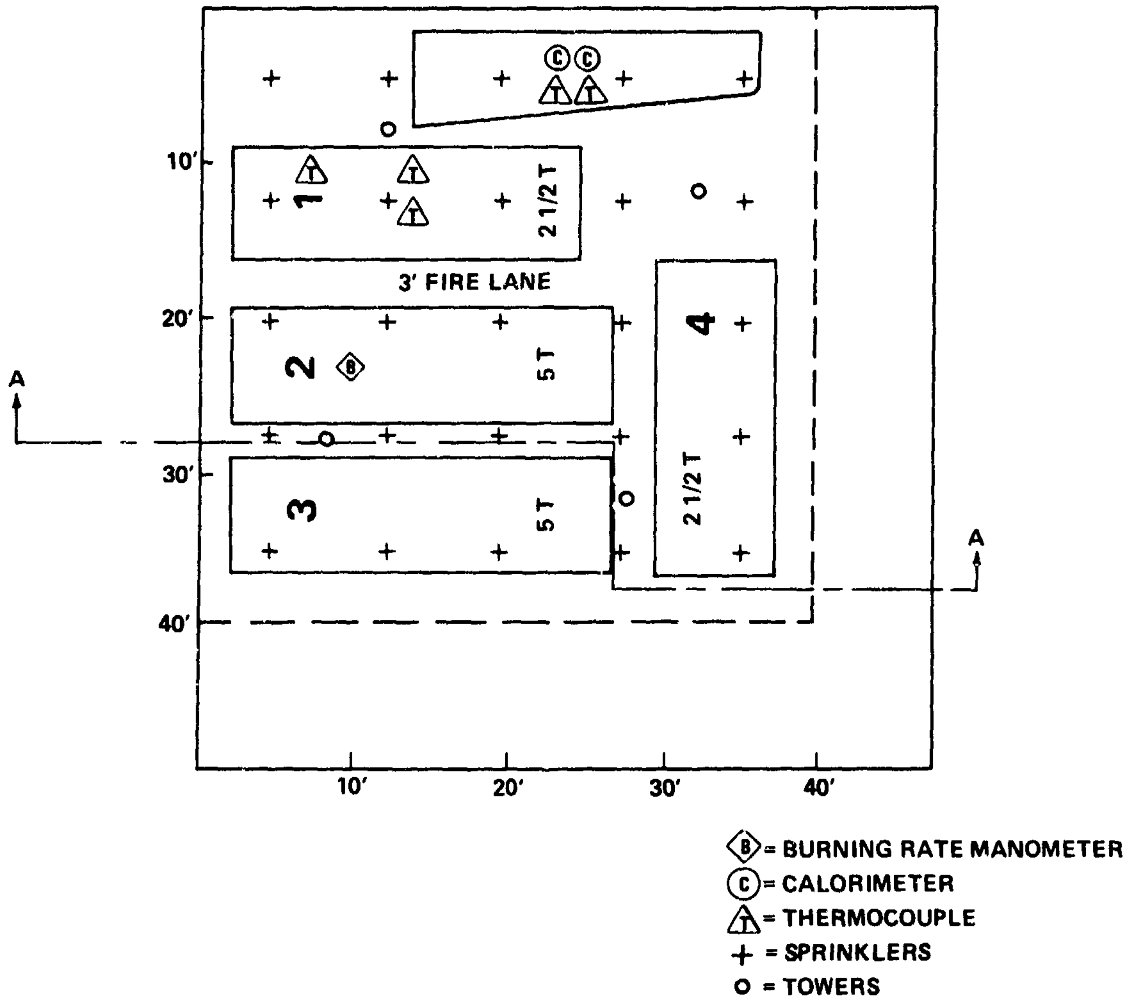
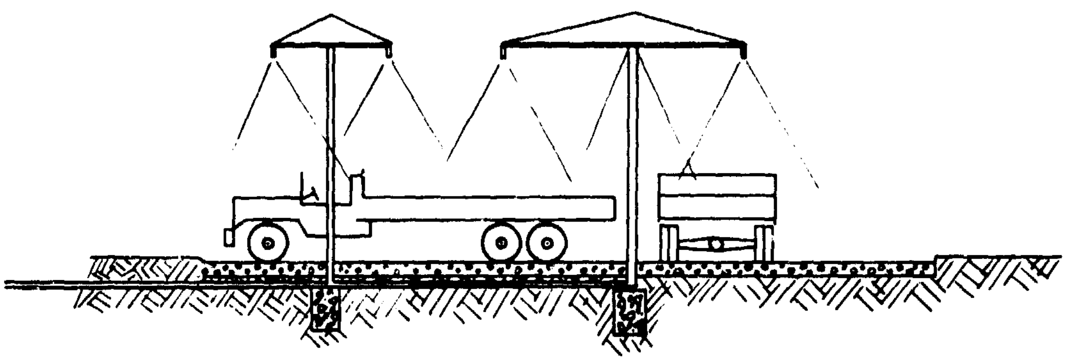


FIG. 5.1 INSTRUMENT LAYOUT PLAN AT SITE 300.





SECTION A–A

FIG. 5.2 LOCATIONS OF SPRINKLERS OVER THE TEST VEHICLES.

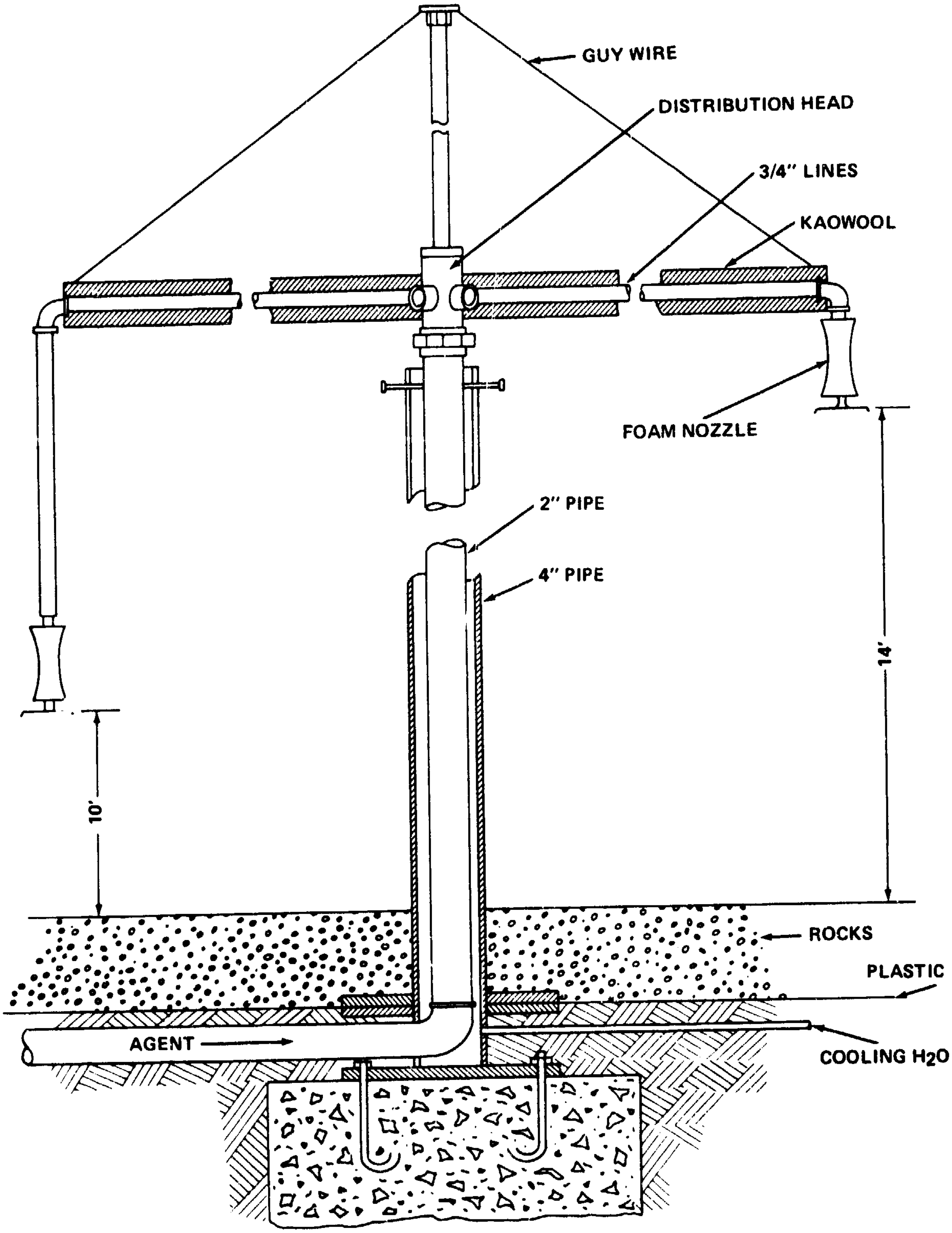


FIG. 5.3 DETAILS OF FOAM TOWER CONSTRUCTION.

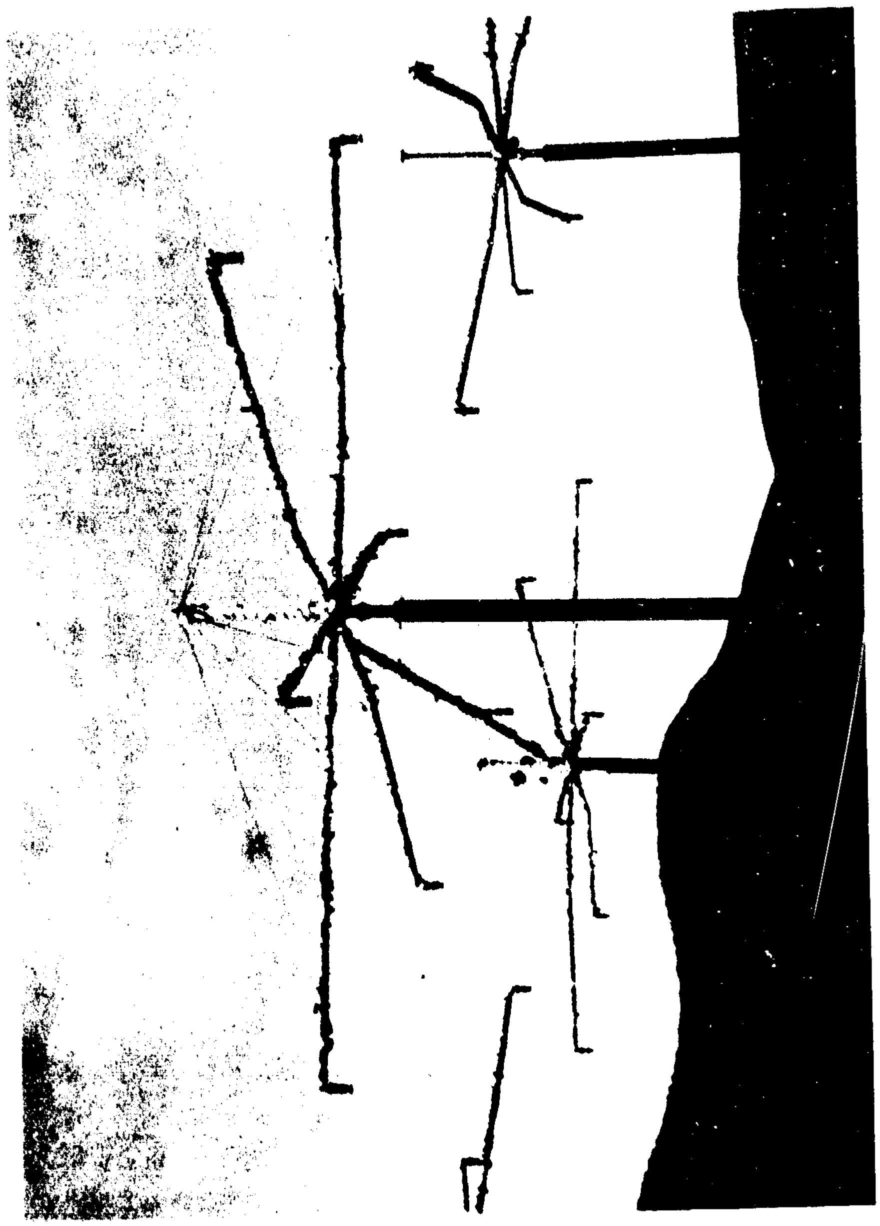


FIG. 5.4 NOZZLES AND DISTRIBUTION LINES IN 14' POSITION ATOP THE FOAM TOWERS

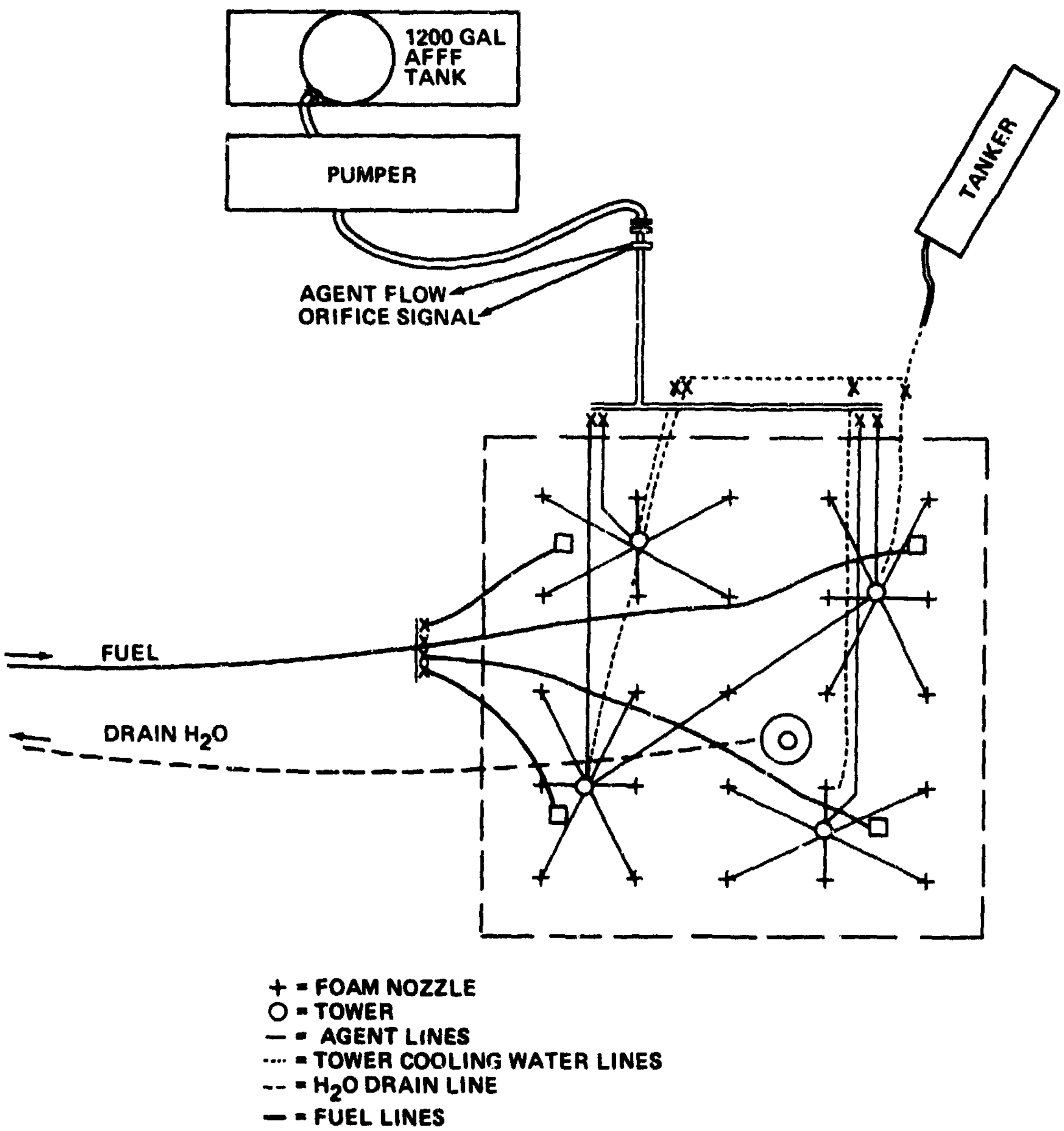


FIG. 5.5 AGENT, WATER, AND FUEL SUPPLY SYSTEMS.

FIG. 5.6 MOPUP PROCEDURES AND EQUIPMENT: (A) BATEL 1 1/2" AFFF NOZZLE, (B) WATER APPLIED WITH 1 1/2" FOG-STRAIGHT STREAM NOZZLE AND 10' APPLICATOR, (C) SCREEN BARRICADE TO CONTAIN HIGH EXPANSION FOAM, BEING APPLIED TO FIRE AISLE BETWEEN TRUCKS.

FIG. 5.7 PENDANT FOAM SPRINKLERS IN OPERATION DURING APPLICATION DENSITY MEASUREMENTS.

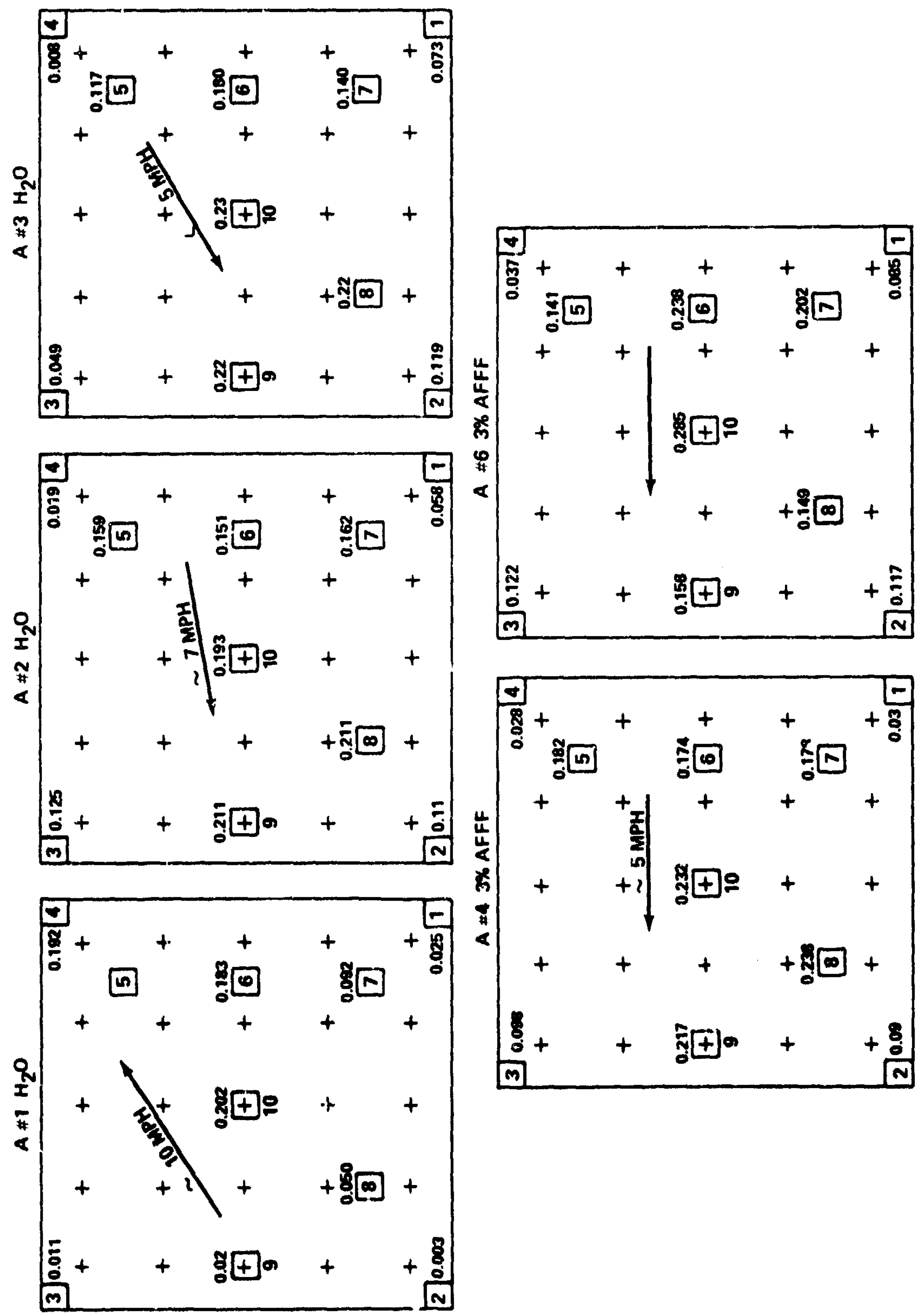


FIG. 5.8 APPLICATION RATES (GPM FT.$^{-2}$) AT VARIOUS SAMPLE PAN POSITIONS-NO-FIRE CONDITIONS.

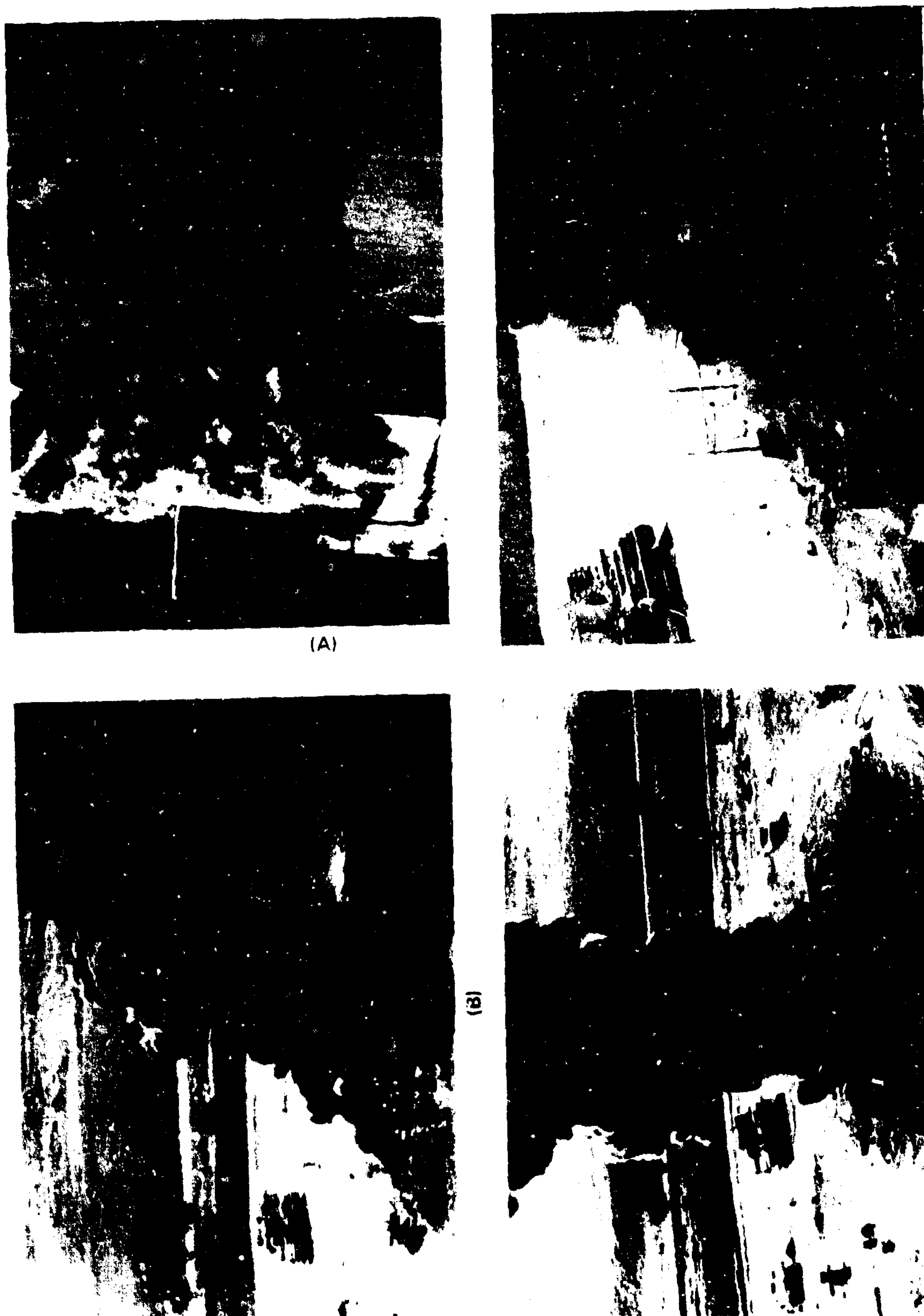


FIG. 5.9 EFFECTS OF WIND AND VEHICLE ON FIRE APPEARANCE, (A) NO WIND, NO VEHICLES, (B) 6 mph WIND, NO VEHICLES, (C) NO WIND, TWO TRUCKS AND AIRCRAFT WIND, (D) 6 mph WIND, 4 TRUCKS AND COLLAPSED AIRCRAFT WING.

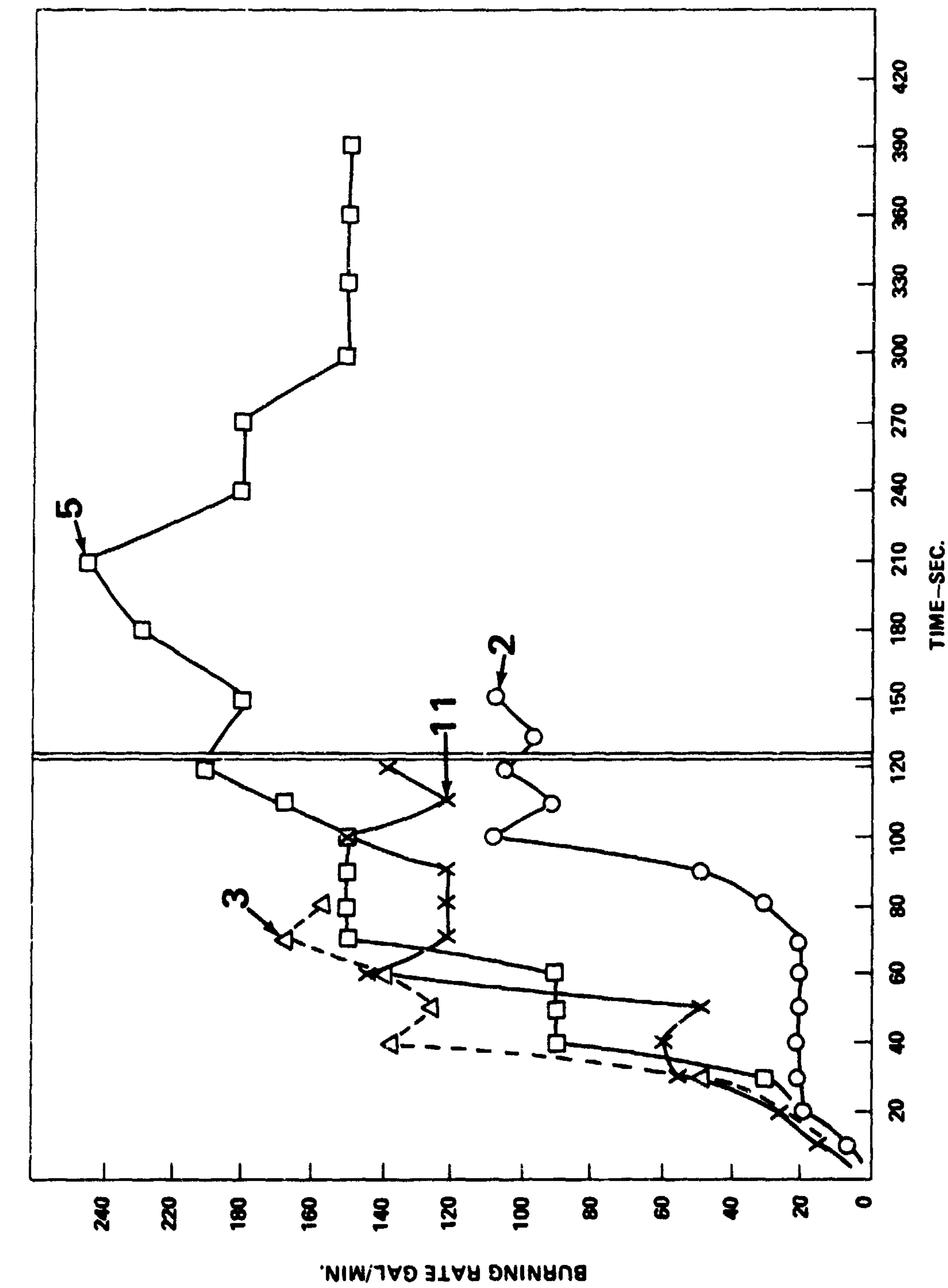


FIG. 5.10 BURNING RATE CHARACTERISTICS FOR VARIOUS COMBINATIONS OF WIND, VEHICLES, AND PREBURN TIMES.

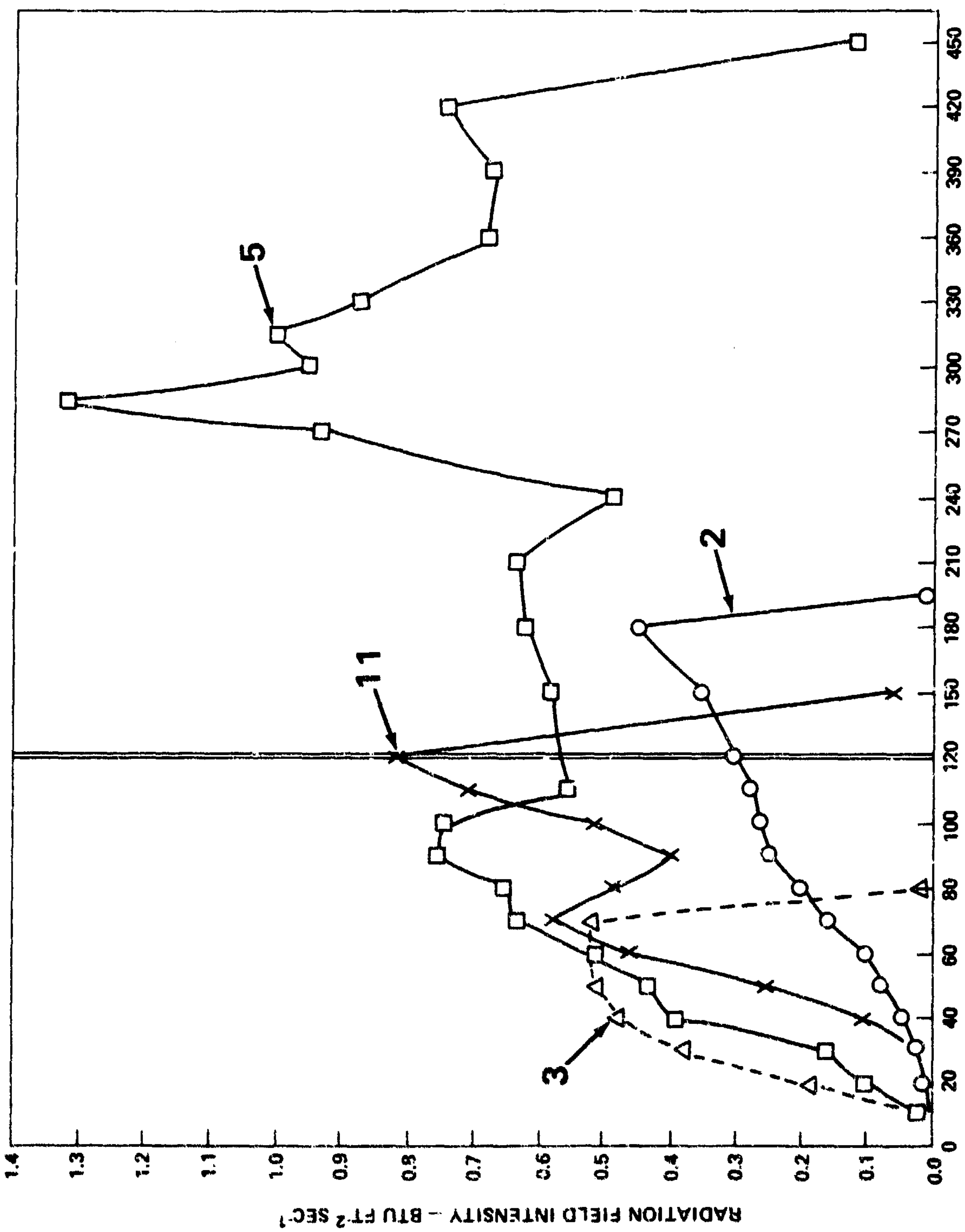
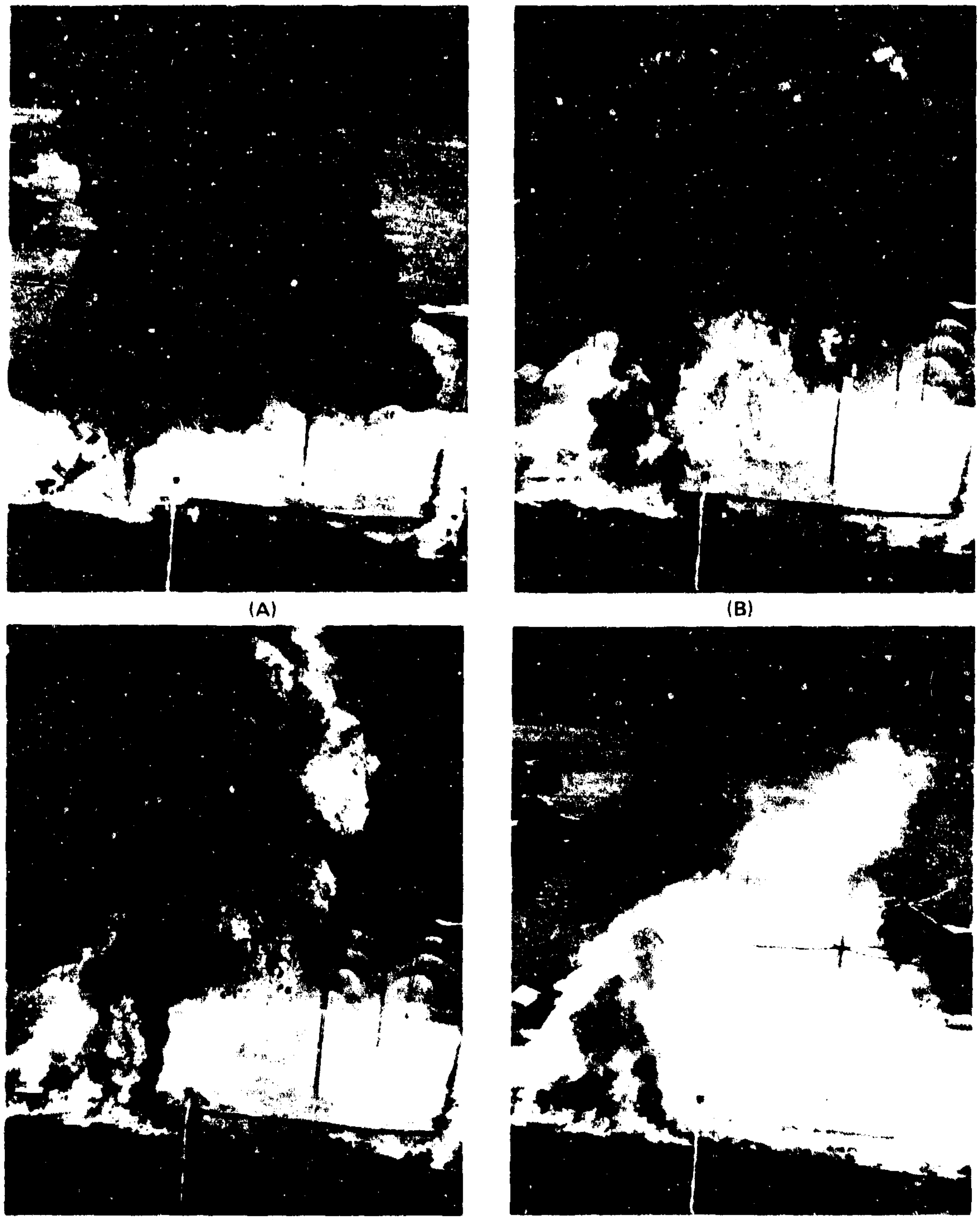
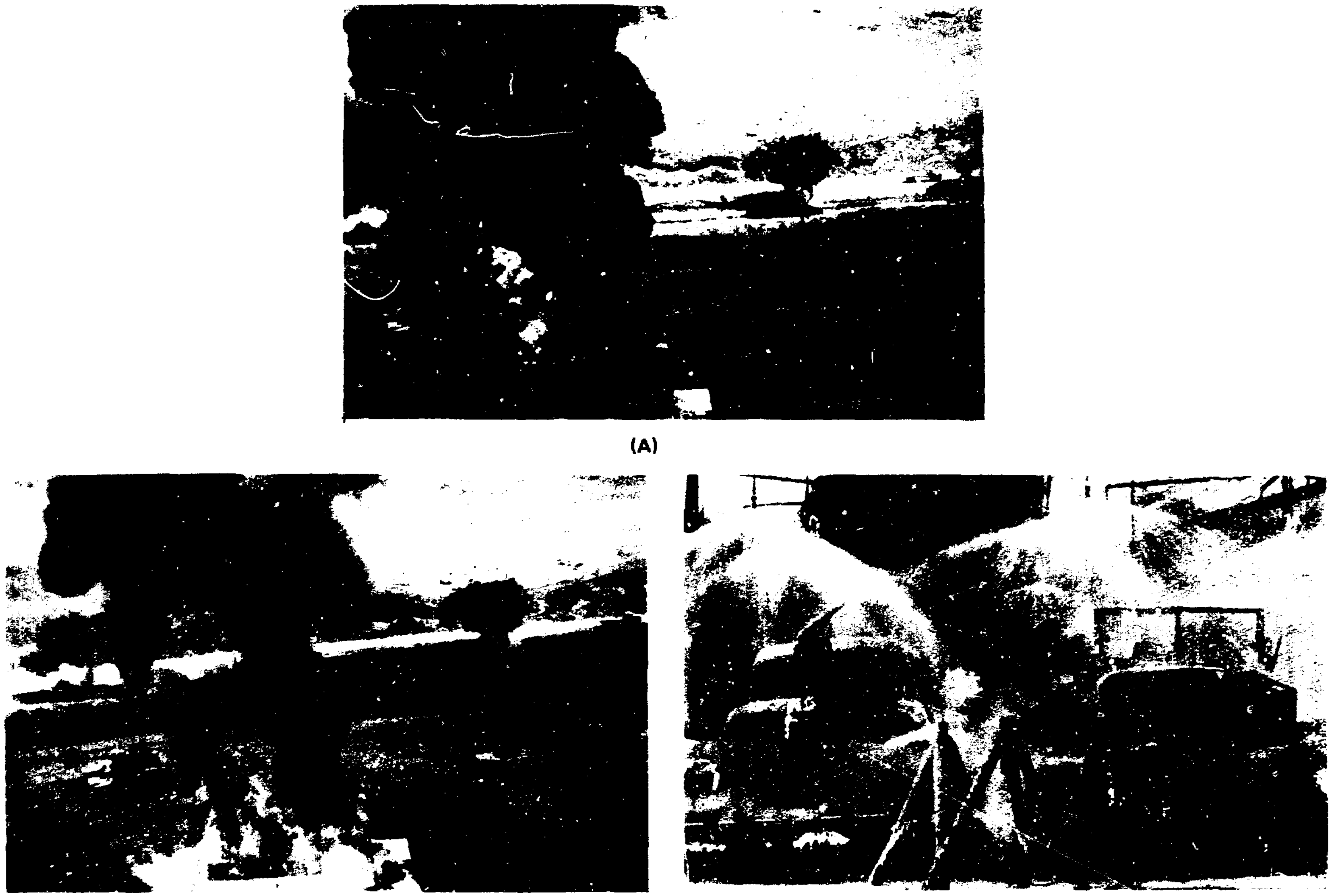


FIG. 5.11 TEMPORAL CHARACTERISTICS OF THE RADIATION FIELD FOR VARIOUS WIND AND VEHICLE CONDITIONS.



(A) (B) (C) (D)

FIG. 5.12 EXTINGUISHMENT OF APPROXIMATELY 1400 FT^2 JP5 FIRE IN ABSENCE OF WIND AND VEHICLES; (A) FIRE AT END OF PREBURN PERIOD, (B) SUPPRESSION COMMENCES, (C) PERIPHERY EXTINGUISHED, (D) FIRE CONTROLLED EXCEPT FOR STRAY FUEL FIRE OUTSIDE THE SPRINKLED AREA.



(A)

(B)

(C)

FIG. 5.13 EXTINGUISHMENT OF 1600 FT^2 JP5 FIRE CONTAINING TWO TRUCKS; (A) FLAMES AT END OF PREBURN PERIOD, (B) FLAMES REDUCED TO TOWER HEIGHT, NO LONGER COALESCE, (C) FLAMES CONFINED TO TIRES AND ADJOINING JP5.

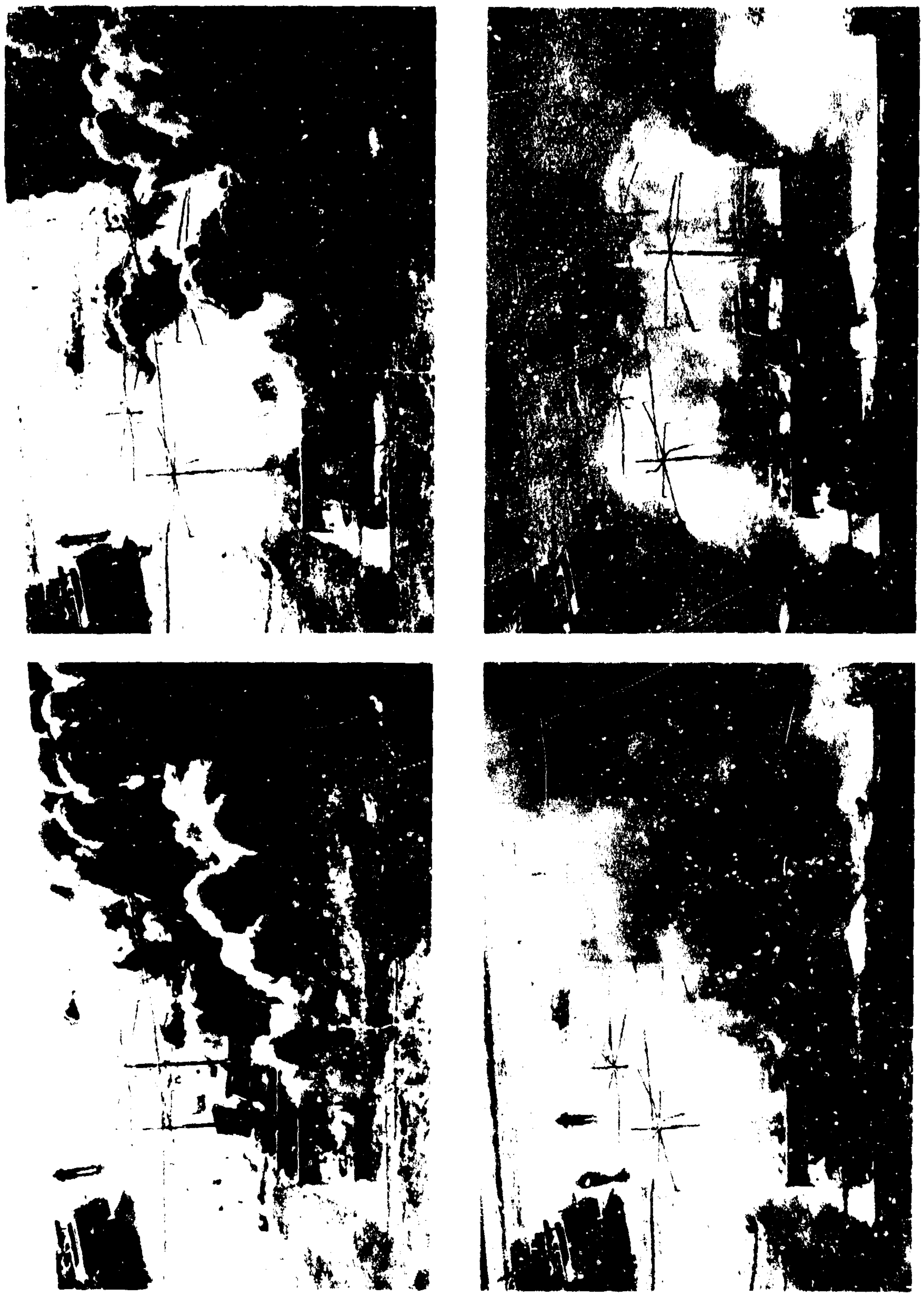


FIG. 5.14 EXTINGUISHMENT OF 1600 FT^2 JP5 FIRE CONTAINING FOUR TRUCKS AND AIRCRAFT WING, TEST 10.

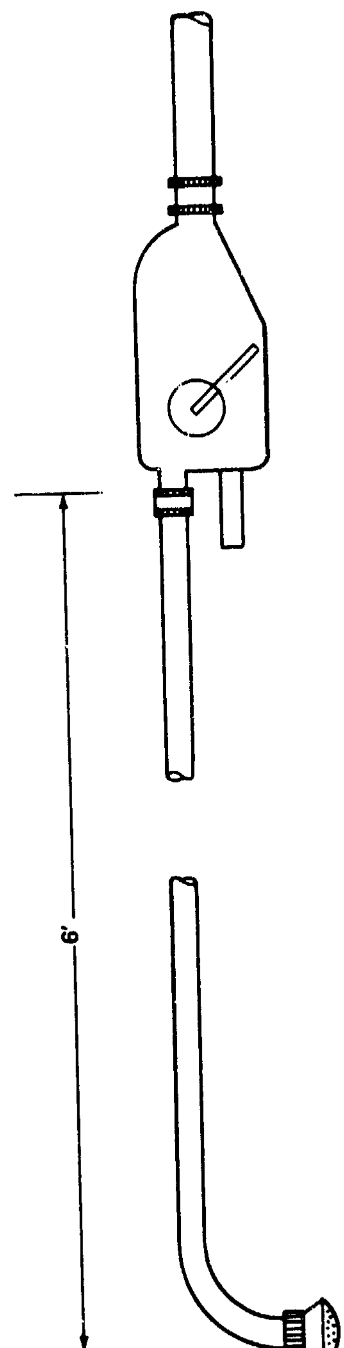


FIG. 5.15 MODIFIED SHORT BEND APPLICATION USED TO EXTINGUISH BETWEEN AND BEHIND DUAL TIRES.

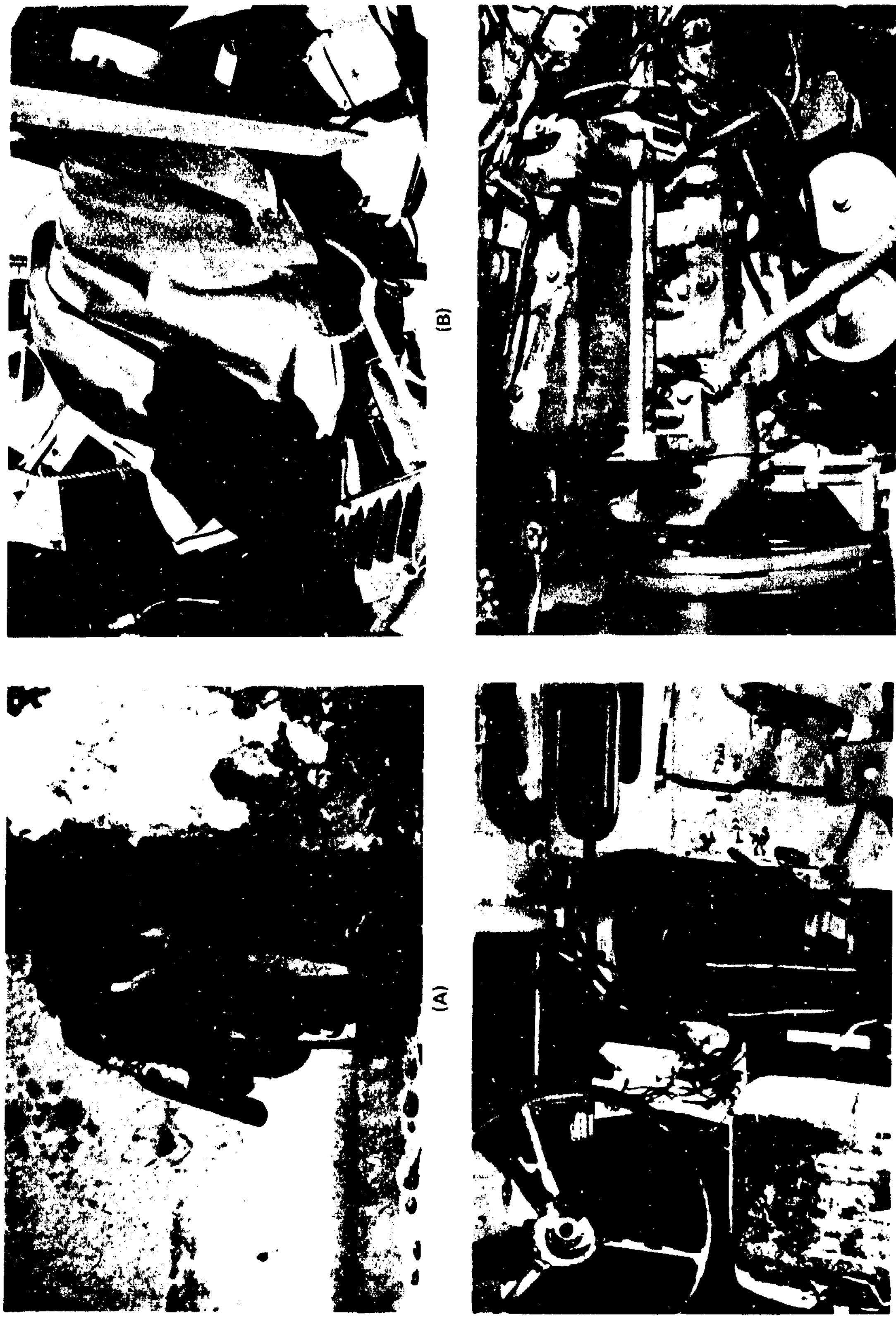


FIG. 5.16 DAMAGE TO COMBUSTIBLE VEHICLE COMPONENTS; (A) SCORCHED BUT USEABLE PIECE OF ROPE, (B) UNDAMAGED CANVAS, ROPE AND WOOD PROTECTED BY TRUCK HEAD, (C) UNDAMAGED UPHOLSTERY AND STEERING WHEEL IN OPEN CAB, (D) RUBBER FANBELTS, HOSES AND CABLES IN OPEN ENGINE COMPARTMENT. (E) CONT'D.

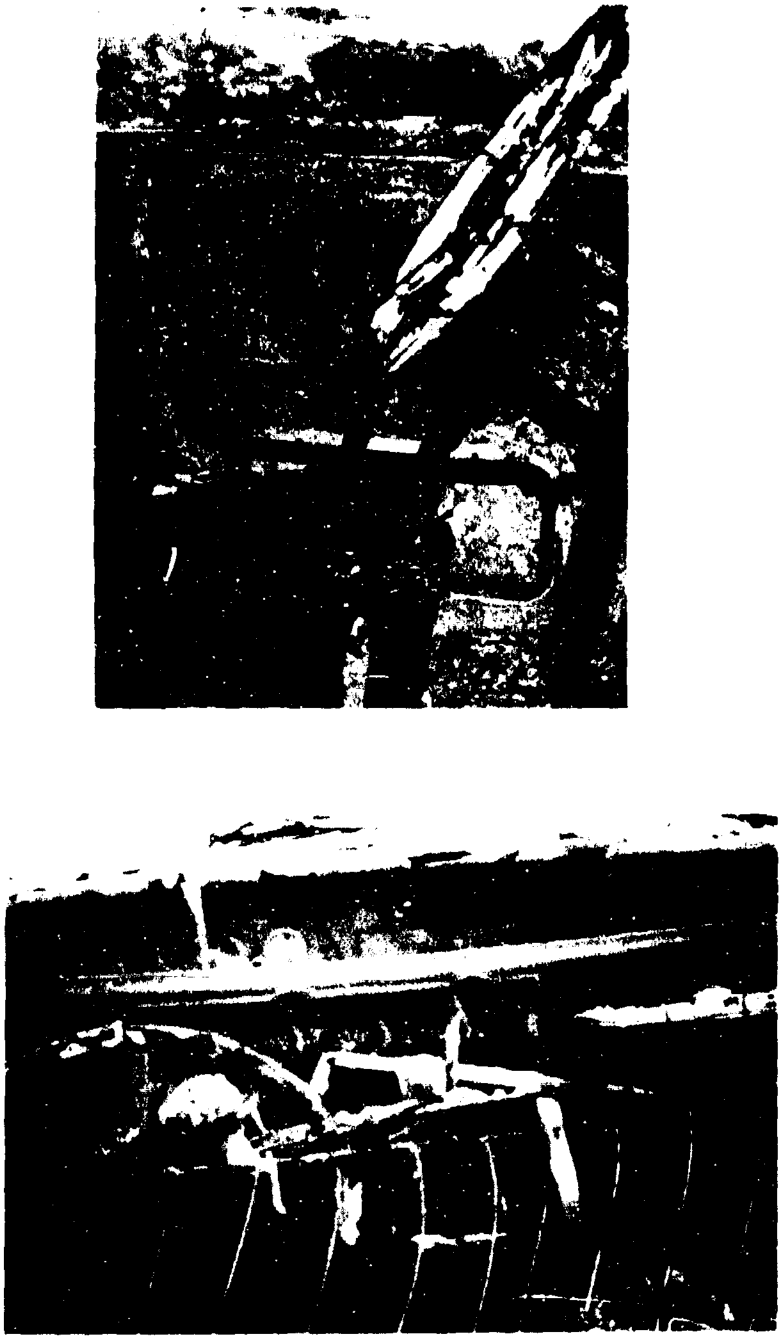
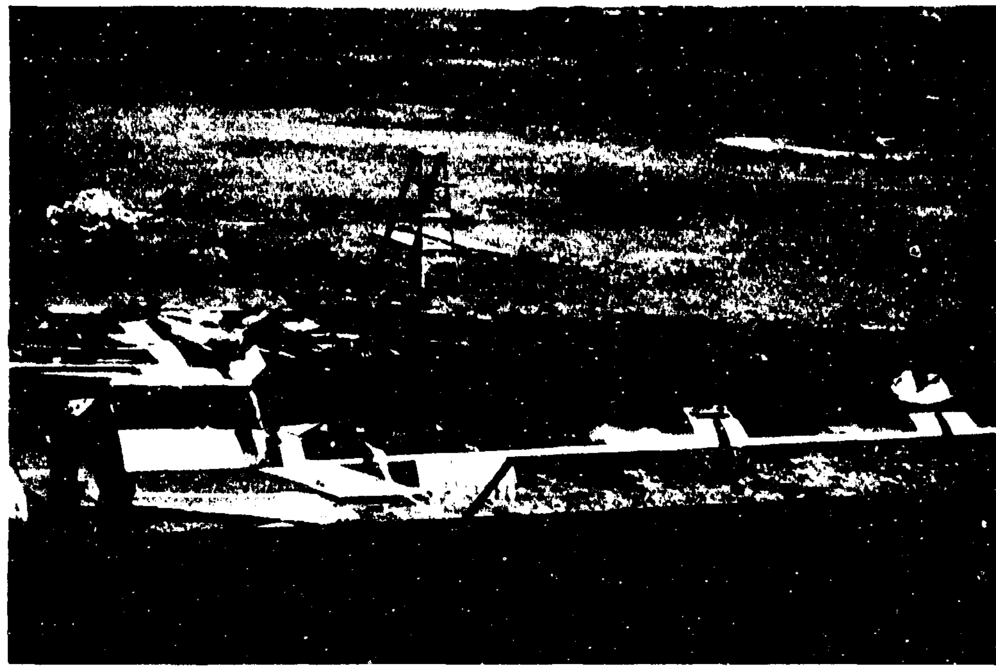


FIG. 5.16 DAMAGE TO COMBUSTIBLE VEHICLE COMPONENTS CONT'D; (E) TRUCK NO. 2 CAB AND (F) TRUCK NO. 1 CAB AFTER 5 MIN PREBURN FIRE.



(A)

(B)

FIG. 5.17 (A) AIRCRAFT WING BEFORE FIRE TEST, (B) WING THAT COLLAPSED DURING THE 30 SEC PREBURN PERIOD.

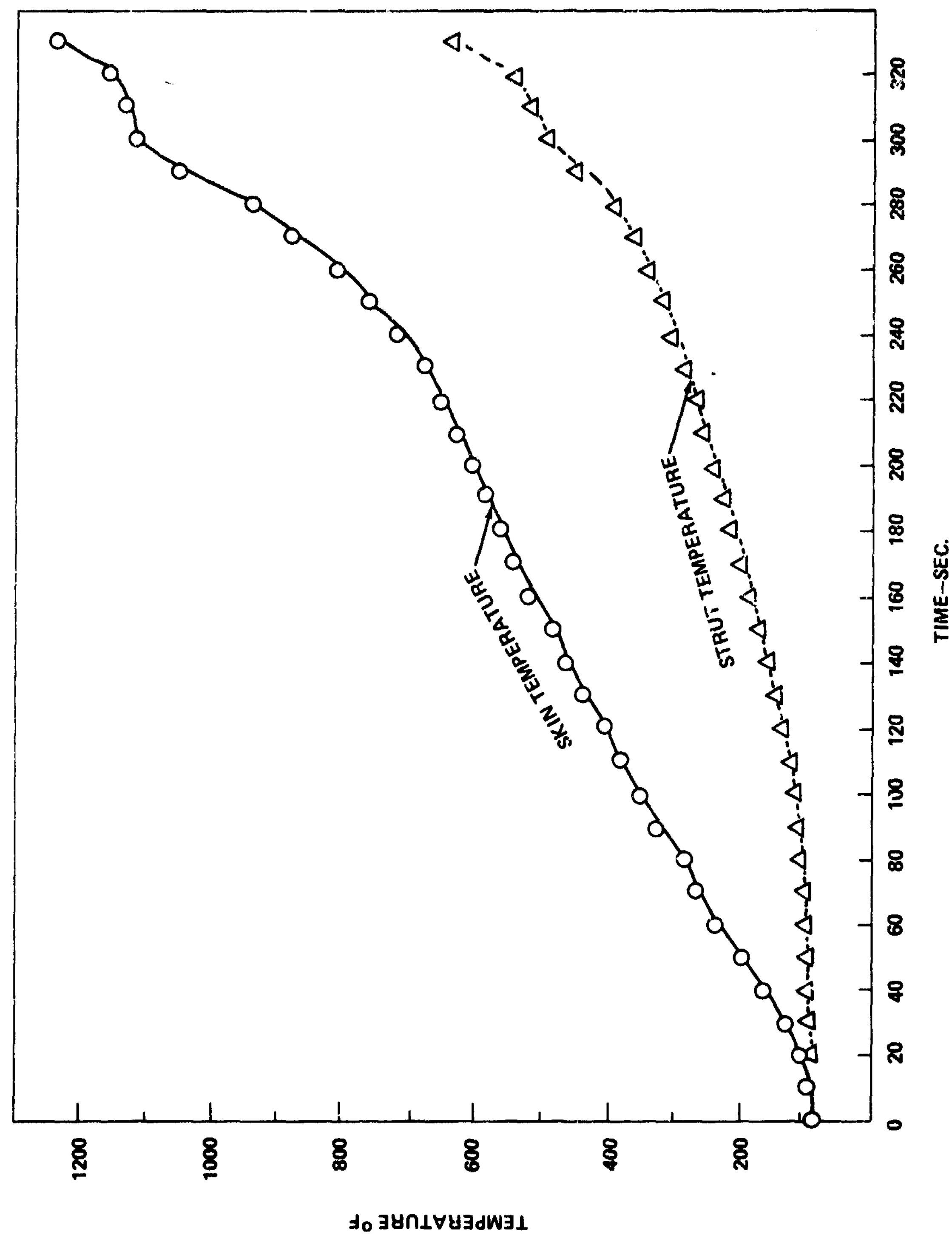


FIG. 5.18 TEMPERATURE OF WING SKIN AND STRUT DURING TEST FIRE NO. 5.

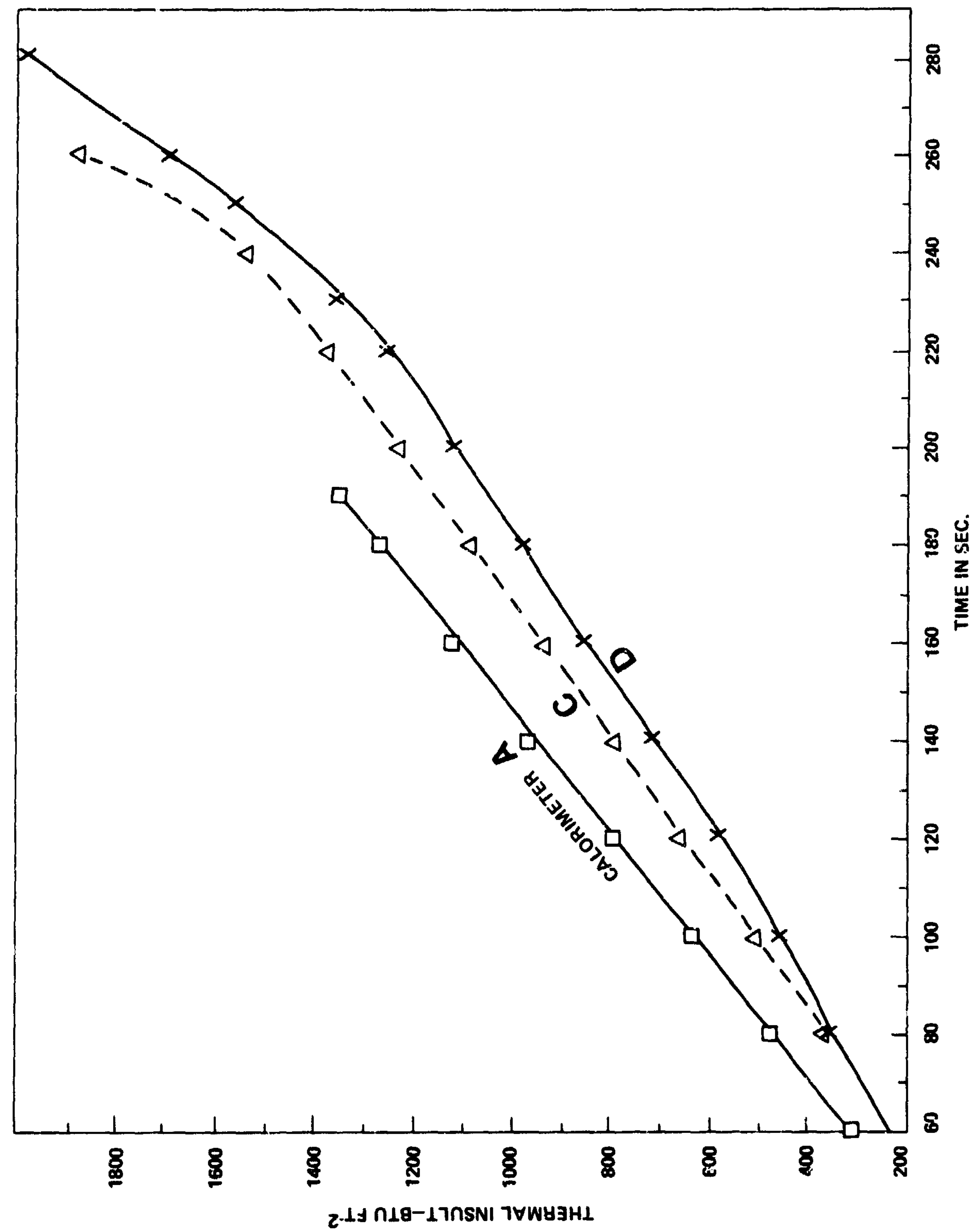


FIG. 5.19 HEAT INSULT OR UNDERSIDE OF WING AS MEASURED BY COPPER SLUG CALORIMETERS DURING TEST FINE NO. 5.

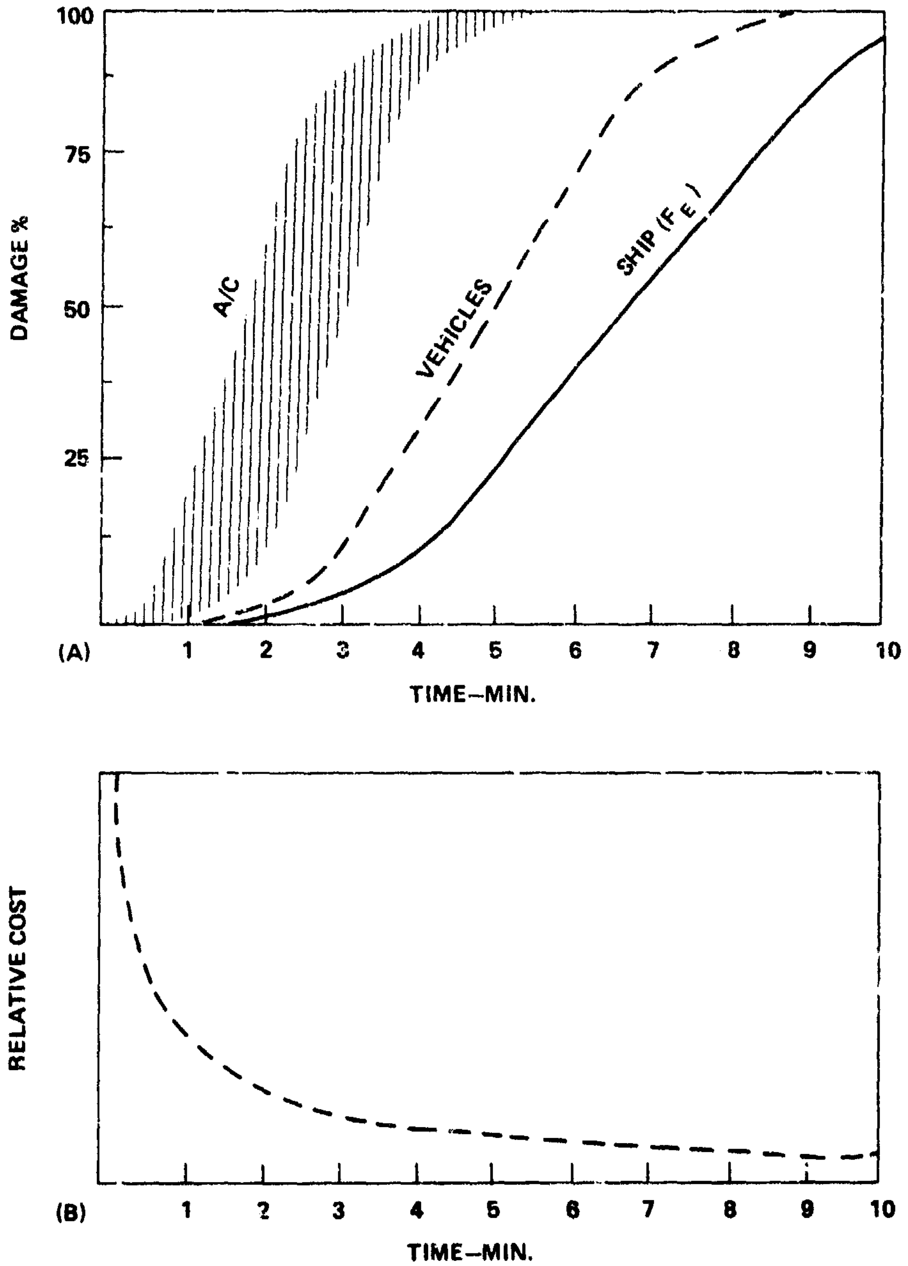


FIG. 6.0 (A) SCHEMATIC REPRESENTATION OF DAMAGE FOR AIRCRAFT, VEHICLES, AND SHIP AS A FUNCTION OF TIME TO EXTINGUISH OR CONTROL THE FIRE. (B) TREND OF EXTINGUISHMENT COSTS VERSUS CONTROL TIME.

TABLE 2.0

AIRCRAFT CHARACTERISTICS

Aircraft Type	Overall Length ft. - in.	Folded Wing Span ft. - in.	Open Wing Span ft. - in.	Height of Folded Wings ft. - in.	Avg. Wing to Ground Distance ft.	Min. Avg. Fuselage to Ground Distance ft.	Maximum Fuselage Diameter ft.	Maximum Foam Flow Distance ft.
F-4J	58' - 3"	27' - 6.5"	38' - 5"	12'	5'	5'	9'	10'
A-TE	46' - 1.5"	23' - 9"	38' - 9"	21'	7'	2'	6'	7.5'
A-6A	54' - 7"	25' - 2"	53'	21'	6'	2'	7'	8'
KA-6S	54' - 7"	25' - 2"	53'	21'	6'	2'	7'	8'
EA-6B	54' - 5"	25' - 2"	53'	21'	6'	2'	7'	8'
RA-5C	68'	42' - 5"	53'	15'	8'	4'	10.5'	11'
E-2B	56' - 4"	29' - 4"	80' - 7"		~ 8'	~ 2'	24'x	13.5'
UH-2C	39' - 7.5"							6.5
F-14	61'	32' - 11.5'Δ	64' - 1.5"□		6'	3.5'	13'	13.5'
S-3A	53' - 4"	29' - 6"	68' - 8"	~ 30'	9'	3'	7'	~ 7'

x = Radome

Δ = Overswept

□ = Unswept

Table 2.1

SHIP VEHICLE STOWAGE CHARACTERISTICS

Item	Ship Type							
	LPH 3	LPH 11	LST 1186	LSD 36	LSD 39	LPH 6	LPD 8	LKA 115
Vehicle stowage area								
Ft²	4,766	4,646	19,933			~ 14,000	13,978	51,117
Minimum overhead clearance, ft.	8'-6"	8'-7"	13'-7"	9'-10"	12'-6"		6' to 10'-2"	7'-10" to 9'-10"
Typical vehicles carried								
M-35 Trucks			x	x	x		x	x
M-54 Trucks			x	x	x		x	x
LVTP7 Amtracks			x	x	x		x	
105 Howitzers				x	x		x	
Bulldozer				x	x			
Crane				x	x			
M-48 Truck				x	x		x	
Jeeps	x	x				x		x

Table 2.2

PERTINENT PARAMETERS

Experimental Variables

1. Fuel
   (a) Type and Characteristics
   (b) Amount
   (c) Distribution
2. Environment
   (a) Fuel Container and Substrate
   (b) Wind, - Velocity and Direction
   (c) Obstructions - Size, Shape and Position
3. Suppression
   (a) Agent - Type and Quality
   (b) Distribution - Pattern and Application Rate

Fire Characteristics

1. Burning Rate
2. Geometry of Flames and Fire Plume
3. Column Aerodynamics and Buoyancy
4. Smoke Production

Evaluation Parameters

1. Critical Application Density
2. Application Density for Extinguishment
3. Control Time
4. Extinguishment Time
5. Thermal Degradation of Objects in Fire

TABLE 3.0

FIRE BEHAVIOR AND EXTINGUISHMENT

Test No.	Type Height Spacing Symbol	Obstruction	Column Angle θ°	Nozzles in Fire Plume No.	Foam Carried Aloft	Time to Full Involvement seconds	Extinguishment Time seconds	Fuel Burned in.	Status of Extinguishment*
17	P-15'-30"x	1	~ 0	1 to 4	Yes	70	60	3/16	1
18	P-15'-30"x	1	60	0	No	35	30.8	1/8	2
19	P-25'-30"+	2	15	0 to 1	Yes	30	40.4	3/32	3
20	P-15'-30"x	2	30	0	No	40	60	5/32	4
21	U-15'-30"□	2	70	0	No	38	20	1/16	1
22	U-25'-30"o	2	~ 0	4 to 0	Yes	95	20	5/32	4
23	U-25'-30"o	3	80	0	No	40	-	9/32	Missed pan
24	U-25'-30"o	3	0	4	Yes	90	80	1/4	5 and 6
25	U-15'-30"□	3	15	0	No	55	35	3/16	3 or 4
26	P-25'-30"+	3	0	4	Yes	105	90	3/16	3
27	P-15'-30"x	3	0 to 15	4 to 0	Yes	60	90.2	1/8	6
28	P-15'-8'*	3	0	4	Yes	80	80	3/16	3 or 4
29	P-25'-8'*	3	20	2	Probably	55	49.2	3/16	4
30	U-25'-8'Δ	3	40	0	No	30	90	5/32	4
31	U-15'-8'∇	3	45	0	Yes	110	90	1/4	6 and 4
32	U-25'-8'Δ	2	0 to 30	1	Yes	100	50	6/32	2
33	U-15'-8'∇	2	~ 0	2	Yes	105	50	1/8	2
34	P-25'-8'*	2	60	0	No	50	60	1/32	2 or 3
35	P-15'-8'*	2	30 to 60	0	Yes	115	85	9/32	2
36	P-15'-8'*	4	15	2 to 0	No	50	85	5/32	2
37	P-15'-8'*	4	15 to 30	0	No	55	60	5/32	2
38	U-15'-8'∇	4	15 to 45	1	No	60	90	1/8	2
39	U-15'-8'∇	4	30 to 45	0	No	60	77	1/16	2
40	U-25'-8'Δ	None	~ 0	4	Yes	140	20	1/8	1
41	U-15'-8'∇	None	15 to 45	2	Yes	50	15	3/32	2
42	P-25'-8'*	None	20 to 60	0	No	50	15	5/32	1
43	P-15'-8'*	None	15 to 45	1	Yes	135	15	7/32	1
44	P-15'-8'*	None	15 to 40	1	?	60	7	29/64	1
45	P-15'-8'*	5	30	0	No	40	24	1/8	1
46	P-15'-8'*	5	15 to 30	1 to 2	?	50	30	1/8	1
47	P-15'-8'*	5	45	0	Yes	60	35	7/64	1

* 1 = All flames extinguished
2 = Flames only in sample dishes
3 = Patch of flames ~ 1 ft^2
4 = Patch of flames 1 to h ft^2
5 = Patch of flames > 4 ft^2 < 1/4 pan
6 = Agent not gaining on fire

TABLE 3.1

APPLICATION RATE AS A FUNCTION OF NOZZLE PARAMETERS

← Type →	Pendent				Parameters			
← Height →	15'		25'		15'		25'	
Spacing	30"	8'	30"	8'	30"	8'	30"	8'
Application Rate GPM/100 ft^2	25 - S	10 - N	17 - S	13 - B	10 - B	10 - B	25 - N	13 - B
	28 - S	12 - B	32 - N	17 - B	13 - S	10 - N	20 - N	8 - S
		11 - S				15 - S		15 - N
		11 - S				8 - B		
		19 - B				15 - S		
		16 - S						
		11 - S						
		16 - B						

N = No wind

S = Slight wind, tilt of flames < 30^{o}

B = Breeze, tilt of flames > 30^{o}

TABLE 3.2

AGENT DENSITY, DISTRIBUTION, AND LOSSES

Test No.	Obstruction	Crystalizing Dish Position No. 1 gal/100 ft^2	No. 2 gal/100 ft^2	No. 3 gal/100 ft^2	No. 4 gal/100 ft^2	No. 5 gal/100 ft^2	Average Application Density gal/100 ft^2	Average Density In Dishes gal/100 ft^2	Average Agent Lost gal/100 ft^2	Agent Lost / Agent Applicatio
19	2	4.5	8.1	33.1	0.52	0	11.2	9.2	1.3	.11
20	2	12.8	24.8	12.9	0.07	0.33	24.7	10.8	13.2	.53
21	2	6.4	2.6	34.2	1.04	5.9	3.2	10.0	>	0
22	2	17.3	26.2	2.4	0.07	6.2	29.3	10.4	18.2	.62
23	3	-	-	-	-	-	-	-	-	-
24	3	10	0.8	11.4	0.9	0.9	26.7	4.8	21.2	.79
25	3	2.8	5.9	7.3	0.03	2.2	8.2	3.6	3.9	.48
26	3	12.9	11.9	3.1	0.03	4.7	48.6	6.5	41.4	.85
27	3	7.6	17.3	5.5	0.4	1.4	40.2	6.4	33.1	.82
28	3	7.6	9	17.9	0.2	0.03	13.1	6.9	5.5	.42
29	3	4.3	4.8	5.5	0.2	6.2	-	4.2	-	-
30	3	7.6	8.8	2.4	2.2	0.1	19.1	4.2	14.2	.74
31	3	5.9	9.3	5.5	2.0	0.1	14.8	4.6	9.5	.64
32	2	5.1	18.6	27.4	0	0	6.5	10.2	>	>
33	2	5.9	9.7	35.6	0.1	0	8.2	10.3	>	>
34	2	4.8	7.9	49.0	0	0	12.5	12.3	>	>
35	2	12.7	18	30	0	0	16.9	12.1	4.1	.24
36	4	9.3	14.2	12.1	7.9	0	15.4	8.7	6.0	.39
37	4	8.6	14.7	11.7	1.4	0	10.9	7.3	2.9	.27
38	4	7.1	11.7	12.3	1.7	0	22.4	6.6	15.1	.67
39	4	7.8	10.7	12.1	0.7	0	10.4	6.3	3.4	.33
40	None	5	2.4	1.6	0.2	0.14	5.0	1.9	2.4	.49
41	None	0.35	0.17	0.35	0.35	0.17	3.5	0.28	2.5	.71
42	None	1.7	1.6	0.35	0.35	0.35	3.9	0.87	2.3	.60
43	None	1.7	1.7	1.2	0.86	1.2	4.4	1.3	2.4	.55
44	None	0.35	0.28	0.24	0.35	0	-	0.24	-	-
45	5	6.9	1.5	2.6	2.3	1.7	6.4	3.0	2.7	.42
46	5	11.6	9.5	1.7	6.2	2.9	5.7	6.4	>	>
47	5	1.0	5.4	2.[illegible]	13.8	5.3	9.5	5.7	3.1	.33

Table 4.0

PRELIMINARY VEHICLE STOWAGE TESTS

Test	% Concentration	Obstruction	Plume Angle From Vertical	Nozzles in Fire Plumb	Foam Carried Aloft	Time to Full Involvement sec (a)	Control Time Inside car sec	Control Time JP-5 Pool sec (b)	Discharge Time sec	Fuel Burned inch	Preburn + a + b sec
48	3	None	~ 60°	0	No	28	NA	4	7.4	1/8	62
49	6	None	~ 60°	0	No	35	NA	5	8.5	3/16	70
50	6	Auto + Pan	30-45	0	No	39	No fire	56	78	1/16	125
51	3	Auto + Pan	10-15	0	No	80	2	83	105	1/8	193
52	3	Auto + Pan	0	4	Yes	80	5	136	165	9/16	336

TABLE 5.0

ENVIRONMENT AND FIRE CHARACTERISTICS

Fire No.	Vehicles	Avg. Wind Velocity MPH	Burning Rate mm/min.	Radiation Field Intensity BTU Ft^{-2} Sec^{-1}								
				R_1	R_2	R_3	R_4	R_5	R_6	R_7	R_8	R_9
1	0	5.3 to 6.2	4.3	.99	-	.20	1.21	.35	.17	1.0	.49	.19
2	0	0 to 1.4	2.0	1.01	.42	-	1.70	.61	.21	1.19	.48	.20
3	0	6.4	4.2	1.08	.51	.024	4.99	1.36	.21	1.11	.58	.34
4	$T_1 + T_2$	5.3	3.8	1.01	.47	.019	1.33	.40	.078	.95	.51	.23
5	$T_1 + T_2 + W$	4.4	4.2	1.47	.62	.03	2.73	.63	.114	1.71	.82	.27
6	$T_1 + T_2$	4.9	3.6	1.34	.60	.03	2.90	.61	.141	1.37	.78	.26
7	$T_1 + T_2 + T_3 + T_4$	3.6	3.8	1.46	.74	-	3.61	.96	.131	1.43	.55	.25
8	$T_1 + T_2 + T_3 + T_4$	3.7 to 6.9	3.8	.98	.46	.021	1.43	.45	.058	1.50	.66	.26
9	$T_1 + T_2 + T_3 + T_4$	4.7	3.7	1.03	.59	.025	1.41	.42	.078	.79	.48	.24
10	$T_1 + T_2 + T_3 + T_4 + W$	4.3	3.7	1.11	.51	.024	1.02	.26	.010	.71	.36	.14
11	$T_1 + T_2 + T_3 + T_4 + W$	5.8	3.7	1.31	.70	-	1.75	.46	.089	.73	.42	.14

T_1 = No. 1 Truck (2 1/2 ton) in Figure 5.2
T_2 = No. 2 Truck (5 ton) in Figure 5.2
T_3 = No. 3 Truck (5 ton) in Figure 5.2
T_4 = No. 4 Truck (2 1/2 ton) in Figure 5.2
W = Wing

TABLE 5.1

TEMPORAL BEHAVIOR OF JP5 FIRES DURING EXTINGUISHMENT

Fire No.	Time to Full Coverage seconds	Preburn Time seconds	Suppression Time to State (1) seconds	Suppression Time to State (3) seconds	Nominal Application* Density gal/100 ft^2	Total Agent Application Time seconds	Total Agent Applied gallons	Agent Concentration percent	Nozzle Height ft	Average Application Rate GPM ft^{-2}*
1	35	47	7.5	-	13.8	35	220	3	14	.23
2	174	3	9.8	-	4.9	12	78.8	3	10	.21
3	15	55	6.5	-	5.1	13	81.2	3	10	.22
			6.5		1.4	15	22.6	3	10	
4	34	32	120	177	76.4	178	1220	3	10	.25
5	36	380	125	162	71.2	181	1140	3	10	.24
6	-	30	-	-	45.6	118	730	3	10	.22
7	105	49	86	139	73.3	169	1175	3	10	.26
8	46	69	13	90	80.4	179	1285	6	10	.27
9	50	38	27	135	80.4	179	1285	3	10	.27
10	101	65	20	35	73.8	181	1180	6	14	.25
11	55	63	32	66	75.0	181	1200	3	14	.25

* Based on 1600 ft^2 Application Area

TABLE 5.2

MAXIMUM TEMPERATURES REACHED AT INSTRUMENTED POINTS FOR TRUCK #1

Fire No.	Drive Shaft °F	Fuel Tank °F	Oil Pan °F
4	615	70	90
5	> 1200	205	-
6	500	70	300
7	> 1200	200	> 1000
8	-	105	310
9	-	110	295
10	-	95	-
11	-	140	-

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